AP Biology Insta-Review
@apbiopenguins

Exam Date & Time:
Monday, May 4th 2026 @ 8:00 AM

The following materials have been constructed using the 2026 CED, the 2020 CED, the 2013 Practice Exam, the 2013 CED, released FRQ questions, and self-created questions.

It is organized with the standards from the CED (Course and Exam Description) followed by questions designed to allow you to refresh your memory on the topics. There might be some repeating as topics overlap and I am isolating each standard individually. This has no association with AP/CollegeBoard and was designed as a resource for review of the content for the AP Biology exam.

After each CED unit, there are multiple choice and/or free response questions with an answer key. Some items were topic assigned using the AP Classroom resource and others were assigned by the author of this document using their best judgement. The multiple choice questions have an explanations section. Remember that I am human and I make mistakes, but I did my best to meet your needs.

During the 2023-2024 school year, I made FRQ videos for the FRQs included in this packet and I have continued their creation.

Check out Daily Review on IG

2025-2026 AP Review Schedule

FEBRUARY 2026

S	M	T	W	T	F	S
1	2 1.1	3 1.2	4 1.3	5 1.4	6 1.5	7
8 Unit 1 Review @ 3pm	9 1.6	10 1.7	11 2.1	12 2.2	13 2.3	14
15	16 2.4	17 2.5	18 2.6	19 2.7	20 2.8	21
22 Unit 2 Review @ 3pm	23 2.9	24 2.10	25 3.1	26 3.2	27 3.3	28

MARCH 2026

S	M	T	W	T	F	S
1 Unit 3 Review @ 3pm	2 3.4	3 3.5	4 4.1	5 4.2	6 4.3	7
8	9 4.4	10 4.5	11 4.6	12 5.1	13 5.2	14
15 Unit 4 Review @ 3pm	16 5.3	17 5.4	18 5.5	19 6.1	20 6.2	21
22 Unit 5 Review @ 3pm	23 6.3	24 6.4	25 6.5	26 6.6	27 6.7	28
29 Unit 6 Review @ 3pm	30 6.8	31 7.1				

APRIL 2026

S	M	T	W	T	F	S
			1 7.2	2 7.3	3 7.4	4
5	6 7.5	7 7.6	8 7.7	9 7.8	10 7.9	11
12 Unit 7 Review @ 3pm	13 7.10	14 7.11	15 7.12	16 8.1	17 8.2	18
19	20 8.3	21 8.4	22 8.5	23 8.6	24 8.7	25 Unit 8 Review @ 3pm
26 CRAM Review @ 3pm	27 2013 Exam #1 - 25	28 2013 Exam #26 - 50	29 2013 Exam #51 – 63, NR	30 Q&A		

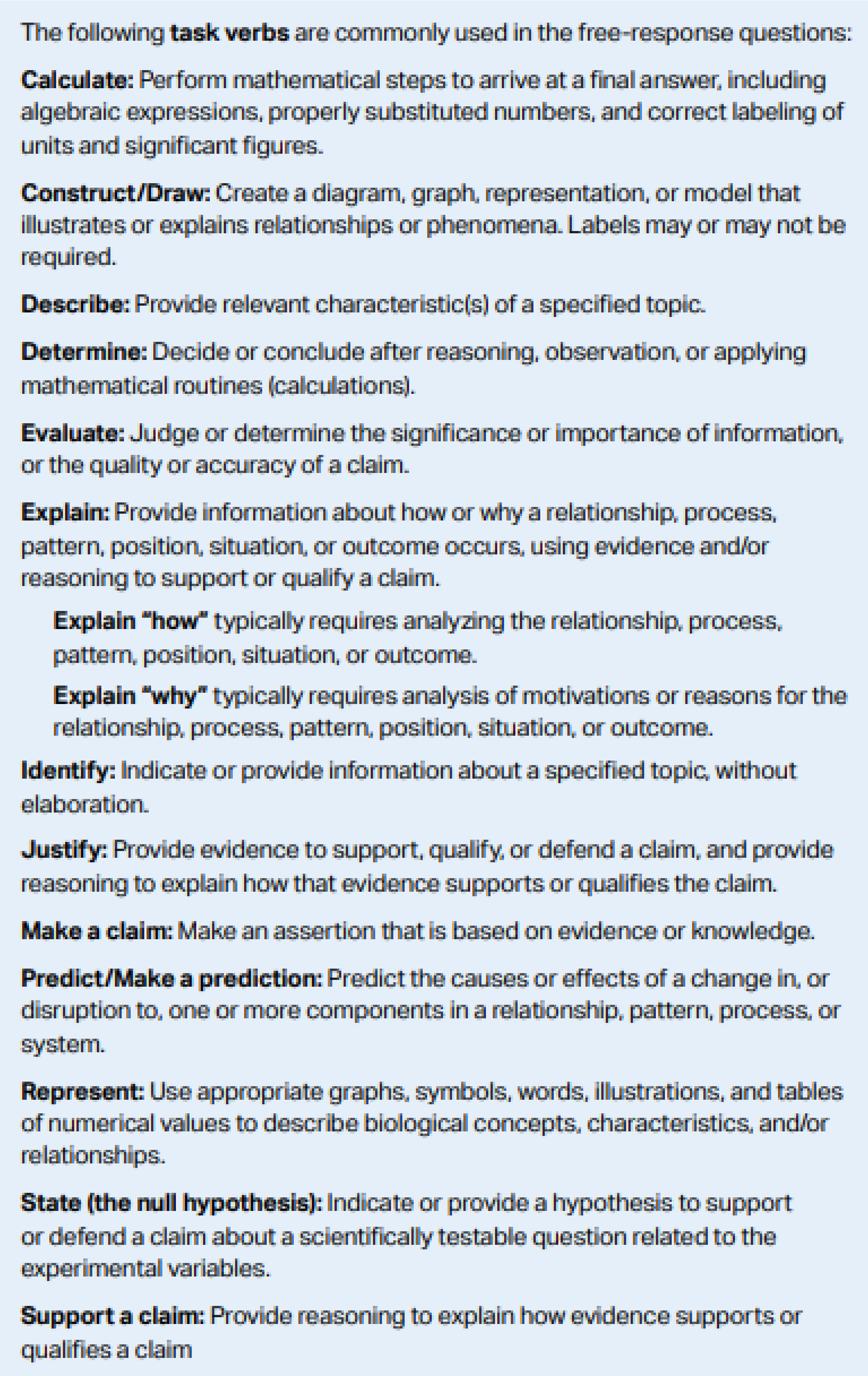
MAY 2026

S	M	T	W	T	F	S
					1 Q&A	2 Q&A
3	4 AP Bio Exam @ 8 AM	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

AP Biology Exam Review

Before we get started, let's look at the science practices that will be used to assess your knowledge on the AP Biology exam. Notice the action verb in each of the skills and note any of these science practices can be used in any question.

Science Practice	Skills
1 – Concept Explanation Explain biological concepts, processes, and models presented in written format	1.A – **Describe** biological concepts and processes.
	1.B – **Explain** biological concepts and processes.
	1.C – **Explain** biological concepts and processes in applied contexts.
2 – Visual Representation Analyze visual representations of biological concepts and processes.	2.A – **Describe** characteristics of visual representations of biological concepts and processes.
	2.B – **Explain** relationships between characteristics of models in both theoretical and applied contexts.
	2.C – **Explain** how biological models relate to larger principles, concepts, processes, systems, or theories.
	2.D – **Represent** relationships within biological models, including mathematical models, diagrams, flow charts, or systems.
3 – Questions and Methods Determine scientific questions and methods	3.A – **Identify** or **pose a testable question** based on an observation, data, or a model.
	3.B – **State** the null hypotheses or predict the results of an experiment.
	3.C – **Identify** experimental procedures that are aligned to the question, including i. Identifying dependent and independent variables. ii. Identifying appropriate controls. iii. Justifying appropriate controls.
	3.D – Propose a new investigation based on an evaluation of the experimental design or evidence.
4 – Representing and Describing Data Represent and describe data	4.A – **Construct** a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components: i. type of graph appropriate for the data ii. axis labeling, including appropriate units and legend iii. scaling iv. accurately plotted data (including error bars when appropriate) v. trend line (when appropriate)
	4.B – **Describe** data from a table or graph, including a. identifying specific data points. b. describing trends and/or patterns in the data. c. describing relationships between variables.
5 – Statistical Tests and Data Analysis Perform statistical tests and mathematical calculations to analyze and interpret data.	5.A – Perform mathematical **calculations**, including i. mathematical equations in the curriculum. ii. means iii. rates iv. ratios v. percentages and percent changes
	5.B – Use confidence intervals and error bars to **estimate** whether sample means are statistically different.
	5.C – Perform chi-square hypothesis testing.
	5.D – Use data to **evaluate** a hypothesis or prediction, including rejecting or failing to reject the null hypothesis.
6 – Argumentation Develop and justify scientific arguments using evidence	6.A – **Make a** scientific **claim.**
	6.B – **Support a claim** with evidence from biological principles, concepts, processes, and data.
	6.C – Provide reasoning to **justify** a claim by connecting evidence to biological theories.
	6.D – **Explain** the relationship between experimental results and larger biological concepts, processes, or theories.
	6.E – **Predict** the causes or effects of a change in, or disruption to, one or more components in a biological system.



The following **task verbs** are commonly used in the free-response questions:

Calculate: Perform mathematical steps to arrive at a final answer, including algebraic expressions, properly substituted numbers, and correct labeling of units and significant figures.

Construct/Draw: Create a diagram, graph, representation, or model that illustrates or explains relationships or phenomena. Labels may or may not be required.

Describe: Provide relevant characteristic(s) of a specified topic.

Determine: Decide or conclude after reasoning, observation, or applying mathematical routines (calculations).

Evaluate: Judge or determine the significance or importance of information, or the quality or accuracy of a claim.

Explain: Provide information about how or why a relationship, process, pattern, position, situation, or outcome occurs, using evidence and/or reasoning to support or qualify a claim.

> **Explain "how"** typically requires analyzing the relationship, process, pattern, position, situation, or outcome.
>
> **Explain "why"** typically requires analysis of motivations or reasons for the relationship, process, pattern, position, situation, or outcome.

Identify: Indicate or provide information about a specified topic, without elaboration.

Justify: Provide evidence to support, qualify, or defend a claim, and provide reasoning to explain how that evidence supports or qualifies the claim.

Make a claim: Make an assertion that is based on evidence or knowledge.

Predict/Make a prediction: Predict the causes or effects of a change in, or disruption to, one or more components in a relationship, pattern, process, or system.

Represent: Use appropriate graphs, symbols, words, illustrations, and tables of numerical values to describe biological concepts, characteristics, and/or relationships.

State (the null hypothesis): Indicate or provide a hypothesis to support or defend a claim about a scientifically testable question related to the experimental variables.

Support a claim: Provide reasoning to explain how evidence supports or qualifies a claim

Pacing Guide for Review Notebook

Done?	Date	Section	Done?	Date	Section	Done?	Date	Section	Done?	Date	Section
	2/1	1.1		3/1	MCQ Practice		4/1	MCQ Practice		5/1	FRQ Practice
	2/2	1.2		3/2	FRQ Practice		4/2	FRQ Practice		5/2	FRQ Practice
	2/3	1.3		3/3	FRQ Practice		4/3	FRQ Practice		5/3	Remember you are an AP Biology Penguin – RELAX TODAY!
	2/4	1.4		3/4	BREAK		4/4	BREAK		5/4	AP Bio Exam @ 8AM
	2/5	1.5		3/5	4.1		4/5	7.1			
	2/6	1.6		3/6	4.2		4/6	7.2			
	2/7	1.7		3/7	4.3		4/7	7.3			
	2/8	MCQ Practice		3/8	4.4		4/8	7.4			
	2/9	BREAK		2/9	4.5		4/9	7.5			
	2/10	2.1		3/10	4.6		4/10	7.6			
	2/11	2.2		3/11	MCQ Practice		4/11	7.7			
	2/12	2.3		3/12	FRQ Practice		4/12	7.8			
	2/13	2.4		3/13	FRQ Practice		4/13	7.9			
	2/14	2.5		3/14	BREAK		4/14	7.10			
	2/15	2.6		3/15	5.1		4/15	7.11			
	2/16	2.7		3/16	5.2		4/16	7.12			
	2/17	2.8		3/17	5.3		4/17	MCQ Practice			
	2/18	2.9		3/18	5.4		4/18	FRQ Practice			
	2/19	2.10		3/19	5.5		4/19	FRQ Practice			
	2/20	MCQ Practice		3/20	MCQ Practice		4/20	FRQ Practice			
	2/21	FRQ Practice		3/21	FRQ Practice		4/21	BREAK			
	2/22	FRQ Practice		3/22	FRQ Practice		4/22	8.1			
	2/23	BREAK		3/23	BREAK		4/23	8.2			
	2/24	3.1		3/24	6.1		4/24	8.3			
	2/25	3.2		3/25	6.2		4/25	8.4			
	2/26	3.3		3/26	6.3		4/26	8.5			
	2/27	3.4		3/27	6.4		4/27	8.6			
	2/28	3.5		3/28	6.5		4/28	8.7			
				3/29	6.6		4/29	MCQ Practice			
				3/30	6.7		4/30	FRQ Practice			
				3/31	6.8						

Tips & Tricks for the AP Exam

Multiple Choice Strategies

- Highlight important words as you read the question or prompt
- "Jot down" notes that could help you answer the question
- Cover up the answer choices and develop your own answer before answer choices cause distractions
- Use the figures or diagrams to help you answer the questions
- Annotate the graphs and show your work on math problems
- Watch your time: 1.5 min/MCQ (watch clock for 10 min/15 Qs)

Free Response Strategies

- Read the question, Read the question, Read the …
- Label your responses (a), (b), (c) & (d)
- Answer in knowledge order
- Do not restate the question
- Additional examples are not scored so clearly denote "first", "second", etc
- Beware of contradictions
- Use the diagrams
- Define your terms
- Graphs: correct type, scale, and labels
- Write clearly and legibly
- Cross out responses to not be scored – a single line is enough
- Pen for FRQs (GRAPH in pencil – do not trace over with pen)
- Watch out for a writing utensil that bleeds or smudges
- Watch your time: 5 min read & renumber, 20 min/long, 8 min/short

Oh Snap Moments

- The direction of "do not skip lines" refers to EVERY LINE, you are fine to skip A LINE between parts of the FRQ.
- If you accidentally respond on the wrong question page, just leave a note on the correct question page where to find your response (i.e. "see Q#2")
  DO NOT RE-WRITE YOUR RESPONSE IN THE CORRECT PLACE.

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	Topic 1.6: Nucleic Acids
	Topic 1.7: Proteins
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	Free Response Practice
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Unit 1: Chemistry of Life

Topic	Learning Objective(s)
1.1 Structure of Water and Hydrogen Bonding	**1.1.A:** Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.
1.2 Elements of Life	**1.2.A:** Describe the composition of macromolecules required by living organisms.
1.3 Introduction of Macromolecules	**1.3.A:** Describe the chemical reactions that build and break biological macromolecules.
1.4 Carbohydrates	**1.4.A:** Describe the structure and function of carbohydrates.
1.5 Lipids	**1.5.A:** Describe the structure and function of lipids.
1.6 Nucleic Acids	**1.6.A:** Describe the structure and function of DNA and RNA.
1.7 Proteins	**1.7.A:** Describe the structure and function of proteins

Additional Resources

Unit 1 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

Topic 1.1: Structure of Water and Hydrogen Bonding

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">1.1.A: Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.</td></tr>
<tr><td>1.1.A.1: Living systems depend on the properties of water to sustain life.
i. Water has polarity, because of the formation of polar covalent bonds between hydrogen and oxygen within water molecules. This polarity contributes to hydrogen bonding between and within biological molecules.
ii. Water has a high specific heat capacity, which allows for the maintenance of homeostatic body temperature within living organisms. Water has a high heat of vaporization, which allows for the evaporative cooling of the surrounding environment. In living organisms, this property allows for body temperature to be maintained.</td><td>☐ I can describe a polar covalent bond.
☐ I can explain what makes water polar.
☐ I can describe a hydrogen bond.
☐ I can explain why water has a high specific heat capacity.
☐ I can describe evaporative cooling.
☐ I can describe how living organisms maintain body temperatures.</td></tr>
</table>

1. What is a polar covalent bond?
    a. Where is the polar covalent bond in a water molecule?
2. Diagram a water molecule including the polar bond and partial charges labeled.
3. Describe why water is considered a polar molecule.
4. What is a hydrogen bond?
5. Where are hydrogen bonds found in water?
6. Draw a diagram of TWO molecules including the hydrogen bond and polar bonds labeled.
7. Identify three properties of water.
8. What is specific heat capacity?
    a. Describe how water has a high specific heat capacity.
9. What is evaporative cooling?
    a. Describe how water is able to facilitate evaporative cooling.
10. Describe two ways that organisms maintain body temperatures.

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.1.A: Explain how the properties of water that result from its polarity and hydrogen bonding affect its biological function.	
1.1.A.2: The hydrogen bonds between adjacent polar water molecules result in cohesion, adhesion, and surface tension.	☐ I can describe a hydrogen bond. ☐ I can identify the properties of water caused by hydrogen bonds. ☐ I can describe cohesion, adhesion, and surface tension. ☐ I can explain what moves water against gravity up a capillary tube. ☐ I can explain what allows a water strider to walk on water.

11. Describe a hydrogen bond.
12. Identify THREE properties of water that are caused by hydrogen bonding.
13. Compare and contrast cohesion and adhesion.
14. What is surface tension?
    a. Which of the properties of water causes surface tension?
15. Using the properties of water, describe how water can move up a capillary tube to move from the roots to the leaves in a plant.
16. Using the properties of water, describe how a water strider can walk on water.

Topic 1.2: Elements of Life

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">1.2.A: Describe the composition of macromolecules required by living organisms.</td></tr>
<tr><td>1.2.A.1: Atoms and molecules from the environment are necessary to build new molecules. Carbon, hydrogen, and oxygen are the most prevalent elements used to build biological molecules such as carbohydrates, proteins, lipids, and nucleic acids. Additionally:
i. Sulfur is used in the building of proteins.
ii. Phosphorus is used in the building of phospholipids (a type of lipid) and nucleic acids.
iii. Nitrogen is used in the building of nucleic acids.</td><td>☐ I can identify the macromolecules required by living organisms.
☐ I can identify the elements found in carbohydrates.
☐ I can identify the elements found in proteins.
☐ I can identify the elements found in lipids.
☐ I can identify the elements found in nucleic acids.
☐ I can identify which macromolecules contain sulfur.
☐ I can identify which macromolecules contain phosphorus.
☐ I can identify which macromolecules contain nitrogen.</td></tr>
</table>

1. What are the four macromolecules?
2. What are the elements found in a carbohydrate?
3. What are three functions of carbohydrates in living organisms?
4. What are the elements found in a protein?
    a. What are the functional groups found in all amino acids?
5. What are three functions of proteins in living organisms?
6. What are the elements found in a lipid?
    a. How are the three different types of lipids different?
7. What are three functions of lipids in living organisms?
8. What are the elements found in nucleic acids?
    a. What are parts found in all nucleotides?
9. What are three functions of nucleic acids in living organisms?
10. Which macromolecule(s) contain sulfur?
11. Which macromolecule(s) contain phosphorus?
12. Which macromolecule(s) contain nitrogen?

Topic 1.3: Introduction to Macromolecules

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.3.A: Describe the chemical reactions that build and break biological macromolecules.	
1.3.A.1: Hydrolysis is a chemical reaction involving the cleaving of covalent bonds. This type of reaction breaks down molecules into smaller molecules. When water is added to the bond between monomers in a polymer, the bond is broken. The hydrogen ion from a water molecule is added to one monomer and the hydroxyl group of the water molecule is added to the other monomer, completing the reaction.	☐ I can describe hydrolysis. ☐ I can identify the bond being broken during hydrolysis. ☐ I can describe the process of hydrolysis. ☐ I can identify the reactants and products in hydrolysis.

1. What is a hydrolysis reaction?
    a. Describe the process of a hydrolysis reaction.
    b. Identify inputs and outputs using a specific example.
2. What type of bond is found in carbohydrate monomers?
    a. Specifically, where is this bond located?
3. What type of bond is found between protein monomers?
    a. Specifically, where is this bond located?
4. What type of bond is found between nucleic acid monomers?
    a. Specifically, where is this bond located?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.3.A: Describe the chemical reactions that build and break biological macromolecules.	
1.3.A.2: Dehydration synthesis occurs when two smaller molecules are joined together through covalent bonding. A hydrogen ion is removed from one monomer and a hydroxyl group is removed from the other. This causes the loss of the equivalent of a water molecule from the reactants and the connection of the two remaining monomers. The connection of many monomers is known as polymerization.	☐ I can describe dehydration synthesis. ☐ I can identify the bond being formed during dehydration synthesis. ☐ I can describe the process of dehydration synthesis. ☐ I can identify the reactants and products in dehydration synthesis.

5. What is a dehydration synthesis reaction?
    a. Describe the process of a dehydration synthesis reaction.
    b. Identify inputs and outputs using a specific example.
6. Diagram a dehydration synthesis reaction of two carbohydrate monomers including a label on the bond.
7. Diagram a dehydration synthesis reaction of two protein monomers including a label on the bond.
8. Diagram a dehydration synthesis reaction of two nucleic acid monomers including a label on the bond.
9. Diagram a dehydration synthesis reaction of glycerol and fatty acids.

Topic 1.4: Carbohydrates

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.4.A: Describe the structure and function of carbohydrates.	
1.4.A.1: Monosaccharides (simple sugars) are the monomers for polysaccharides (complex carbohydrates). These monomers are connected by covalent bonds to form polymers such as complex carbohydrates, which may be linear or branched. ☒ **Exclusion Statement:** *The molecular structure of specific carbohydrate polymers is beyond the scope of the AP Exam.*	☐ I can identify the monomer and polymer of carbohydrates. ☐ I can describe the structural components of the monomer of a carbohydrate. ☐ I can identify the bond between carbohydrate monomers. ☐ I can describe the structures of complex carbohydrates. ☐ I can describe the difference between the bonds of starch and cellulose. ☐ I can describe the functions of carbohydrates.

1. What is the monomer of a carbohydrate?
    a. Identify the components of the monomer.
    b. Diagram a carbohydrate monomer labeling the components
    c. Diagram a disaccharide labeling the bond between the monomers.
2. What type of bond is found between carbohydrate monomers?
3. Describe the structures of a monosaccharide and a polysaccharide.
4. Starch vs. Cellulose
    a. Describe the structures of starch and cellulose.
    b. What type of bond is found in starch?
    c. What type of bond is found in cellulose?
    d. Which bond can be broken by animals?
5. Describe two functions of carbohydrates.

Topic 1.5: Lipids

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.5.A: Describe the structure and function of lipids.	
1.5.A.1: Lipids are typically nonpolar, hydrophobic molecules whose structure and function are derived from the way their subcomponents are assembled. Fatty acids can be described as either saturated or unsaturated. i. Saturated fatty acids contain only single bonds between carbon atoms. ii. Unsaturated fatty acids contain at least one double bond between carbon atoms, which causes the carbon chain to kink. iii. The more double bonds in a fatty acid tail, the more unsaturated the lipid becomes. iv. The more unsaturated a lipid is, the more liquid it is at room temperature.	☐ I can describe the properties of lipids. ☐ I can identify saturated and unsaturated fatty acids. ☐ I can describe the effect of decreasing saturation on the fatty acid at room temperature.

1. Identify the property of lipids.
    a. How is this different than the other macromolecules?
2. Describe the structure of a saturated fatty acid.
3. Describe the structure of an unsaturated fatty acid.
4. How does the level of saturation affect the fatty acid at room temperature?
    a. What would happen if the level of saturation was increased?
    b. What would happen if the level of saturation was decreased?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
1.5.A: Describe the structure and function of lipids.	
1.5.A.2: Lipids provide a variety of functions for living organisms. Some examples of lipids are fats, steroids including cholesterol, and phospholipids. i. Fats provide energy storage and support cell function. In some cases, they can also provide insulation to help keep mammals warm. ii. Steroids are hormones that support physiological functions including growth and development, energy metabolism, and homeostasis. iii. Cholesterol provides essential structural stability to animal cell membranes. iv. Phospholipids group together to form the lipid bilayers found in plasma and cell membranes	☐ I can identify functions of lipids for living organisms. ☐ I can identify three examples of lipid macromolecules. ☐ I can describe the function of fats, steroids, cholesterol, and phospholipids. ☐ I can describe the effect of level of saturation on function of lipids.

⌧ **Exclusion Statement:** *The molecular structure of specific lipids is beyond the scope of the AP Exam.*	

5. Identify the three main types of lipid macromolecules.
6. Describe the structure of a fat molecule.
    a. Identify the function of fats.
7. Describe the general structure of steroids.
8. How does the structure of cholesterol compare?
9. Describe the function of steroids.
10. Describe the function of cholesterol.
11. Diagram and label the structure of a phospholipid.
12. Identify the function of phospholipids.
13. How does the structure of saturated and unsaturated fatty acids differ?
    b. How does the level of saturation affect the function of the lipid?

Topic 1.6: Nucleic Acids

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.6.A: Describe the structure and function of DNA and RNA.	
1.6.A.1: In nucleic acids (DNA and RNA), biological information is encoded in sequences of nucleotide monomers. Each nucleotide has the following structural components: a five-carbon sugar (deoxyribose or ribose), a phosphate, and a nitrogenous base (adenine, thymine, guanine, cytosine, or uracil)	☐ I can identify the structural components of the monomer of a nucleic acid. ☐ I can identify the five nitrogenous bases.

1. What is the monomer of a nucleic acid?
    a. Diagram the monomer of a nucleic acid and label the structural components.
2. Identify the FIVE nitrogenous bases.
3. Describe the difference between a purine and pyrimidine.
    a. Identify which nitrogenous bases are purines.
    b. Identify which nitrogenous bases are pyrimidines.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.6.A: Describe the structure and function of DNA and RNA.	
1.6.A.2: Nucleic acids have a linear sequence of nucleotides that have ends, defined by the 3' (three prime) hydroxyl and 5' (five prime) phosphates of the sugar in the nucleotide. During nucleic acid synthesis, nucleotides are added to the 3' end of the growing strand, resulting in the formation of covalent bonds between nucleotides. ☒ **Exclusion Statement:** *The molecular structure of specific nucleotides is beyond the scope of the AP Exam.*	☐ I can identify the ends of a nucleic acid. ☐ I can describe the directionality of a nucleic acid. ☐ I can identify the growing end of a nucleic acid strand.

4. Describe the structure of the nucleic acid polymer.
5. What are the ends called and what functional group is found at each end?
6. Describe the directionality of a nucleic acid.
    a. Which end is the location of the growing nucleic acid strand?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.6.A: Describe the structure and function of DNA and RNA.	
1.6.A.3: DNA is structured as an antiparallel double helix, with two strands of nucleotides running in opposite 5' to 3' orientation. In DNA, adenine nucleotides pair with thymine nucleotides via hydrogen bonds (A-T), and cytosine nucleotides pair with guanine nucleotides via hydrogen bonds (C-G). In RNA, adenine pairs with uracil (A-U).	☐ I can describe the structure of DNA. ☐ I can identify the base pairs found in DNA. ☐ I can identify the base pairs found in RNA.

7. Describe the structure of DNA.
8. What are the complementary base pairings found in DNA?
9. What are the complementary base pairings found in RNA?
10. What type of bond occurs between complementary base pairings in DNA or RNA?
    a. Describe or diagram where this bond is located.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.6.A; Describe the structure and function of DNA and RNA.	
1.6.A.4: Structural differences between DNA and RNA include: i. DNA contains the sugar deoxyribose, and RNA contains the sugar ribose. ii. DNA contains the nitrogenous base thymine, and RNA contains the nitrogenous base uracil. DNA is typically double stranded, while RNA is typically single stranded.	☐ I can describe the structural differences between DNA and RNA.

11. What are the three components of a DNA or RNA monomer?
12. Identify differences between DNA and RNA using the following chart:

	DNA	RNA
Pentose Sugar		
Nitrogenous Base Difference		
Strandedness (traditionally)		
Directionality		▨

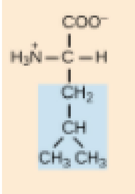
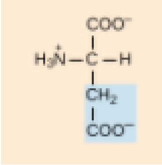
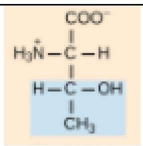
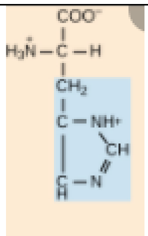
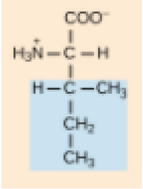
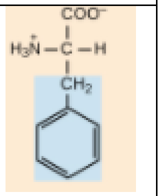
Topic 1.7: Proteins

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.7.A; Describe the structure and function of proteins	
1.7.A.1: Proteins comprise linear chains of amino acids connected by the formation of covalent (peptide) bonds that form between a carboxyl group (–COOH) of one amino acid and an amine group (–NH)$_2$ of the next amino acid, resulting in a growing peptide chain.	☐ I can identify the bond between protein monomers. ☐ I can describe the structure of the carboxyl and amino groups. ☐ I can describe dehydration synthesis in a growing peptide chain.

1. Describe the bonding between protein monomers including the functional group involved.
2. Diagram the functional groups of carboxyl group and amino group.
3. What are the ends of a protein called and what is found at each end?
    a. Diagram the dehydration synthesis reaction of a growing polypeptide chain including a label for the location of the growing polypeptide strand.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.7.A; Describe the structure and function of proteins	
1.7.A.2: Amino acids are composed of a central carbon atom with a hydrogen atom, a carboxyl group, an amine group, and a variable R group covalently bound to it. The R group of an amino acid can be categorized by three possible chemical properties: hydrophobic/nonpolar, hydrophilic/polar, or ionic. The interactions of these R groups determine the structure and function of that region of the protein.	☐ I can identify the four structural components of the monomer of a protein. ☐ I can identify an R group as hydrophobic, hydrophilic, or ionic. ☐ I can describe the effect to structure and function of R group interactions.

4. What is the monomer of proteins?
    a. Identify the components of the monomer.
5. Describe how to determine the polarity of an R group.
6. Using the blue shaded R group, Identify the group as hydrophobic, hydrophilic, or charged? (Hint: focus on the polarity of the molecules involved)

Polarity						
						

7. Describe how a nonpolar to polar R group substitution changes the structure and function of a protein.

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">1.7.A; Describe the structure and function of proteins</td></tr>
<tr><td>1.7.A.3: The specific sequence of amino acids in proteins determines the primary structure of a polypeptide as well as the overall shape of the protein.
☒ Exclusion Statement:
<i>The molecular structure of specific nucleotides is beyond the scope of the AP Exam.</i></td><td>☐ I can describe the primary structure.
☐ I can describe the function of the primary structure.</td></tr>
</table>

8. What is the primary structure of a protein?
9. What type of bond is involved with the primary structure of a protein?
10. Diagram a primary structure of a protein labeling the components and bond.
11. Describe the function of the primary structure.
12. How would an amino acid change affect the primary structure?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">1.7.A; Describe the structure and function of proteins</td></tr>
<tr><td>1.7.A.4: Secondary structures of proteins are made through the local folding that forms from interactions between atoms of the polypeptide backbone of the amino acid chain. Hydrogen bonding forms shapes such as alpha-helices and beta-pleated sheets.</td><td>☐ I can describe the secondary structure.
☐ I can identify the type of bonding found in the secondary structure.
☐ I can describe the two shapes formed from hydrogen bonding.</td></tr>
</table>

13. What is the secondary structure of a protein?
14. What type of bond is involved with the secondary structure of a protein?
15. Describe the two structural shapes formed from bonding in the secondary structure.
16. Diagram a secondary structure of a protein labeling the components, bond, and the structural shape.
17. Describe the function of the secondary structure.
18. How would an amino acid change affect the secondary structure?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">1.7.A; Describe the structure and function of proteins</td></tr>
<tr><td>1.7.A.5: The three-dimensional shape of the tertiary structure of a protein results from the formation of hydrogen bonds, hydrophobic interactions, ionic interactions, or disulfide bridges.</td><td>☐ I can describe the tertiary structure.
☐ I can identify the type of bonding found in the tertiary structure.</td></tr>
</table>

19. What is the tertiary structure of a protein?
20. What type of bond(s) is/are involved with the tertiary structure of a protein.

21. Diagram a tertiary structure of a protein labeling the components and bond(s).
22. Describe the function of the tertiary structure.
23. How would an amino acid change affect the tertiary structure?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
1.7.A: Describe the structure and function of proteins	
1.7.A.6: The quaternary structure arises from interactions between multiple polypeptides. All four levels of a protein structure determine the function of a protein.	☐ I can describe the quaternary structure. ☐ I can describe how the structure determines the function of a protein.

24. What is the quaternary structure of a protein?
25. What type of bond(s) is/are involved with the quaternary structure of a protein.
26. Diagram a quaternary structure of a protein labeling the components and bond(s).
27. Describe the function of the quaternary structure.
28. How would an amino acid change affect the quaternary structure?

Multiple Choice Practice

1. Scientists examined the folded structure of a purified protein resuspended in water and found that amino acids with nonpolar R groups were primarily buried in the middle of the protein, whereas amino acids with polar R groups were primarily on the surface of the protein. Which of the following best explains the location of the amino acids in the folded protein?
    a. Polar R groups on the surface of the protein can form ionic bonds with the charged ends of the water molecules.
    b. Polar R groups are too bulky to fit in the middle of the protein and are pushed toward the protein's surface.
    c. Nonpolar R groups that cannot form hydrogen bonds with water are pushed into the middle of the protein.
    d. Nonpolar R groups from different parts of the protein form covalent bonds with each other to maintain the protein's structure.

2. Rosalind Franklin's x-ray diffraction images taken in the 1950s most directly support which of the following claims about DNA?
    a. The ratios of base pairs are constant.
    b. The nucleotide sequence determines genetic information.
    c. The two strands of DNA are antiparallel.
    d. The basic molecular structure is a helix.

3. Which of the following does not result from hydrogen bonding in water molecules?
    a. Cohesion
    b. Adhesion
    c. Surface Tension
    d. Dissolving fats

4. Why is water considered polar?
    a. Nonpolar covalent bonds in structure
    b. Ionic bonds in structure
    c. Polar covalent bonds in structure
    d. Hydrophobic interaction in structure

5. Which macromolecule(s) have nitrogen?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Nucleic Acids & Proteins

6. Which macromolecule(s) have phosphorus?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Fats

7. Which macromolecule(s) have sulfur?
    a. Carbohydrates
    b. Proteins
    c. Nucleic Acids
    d. Fats

8. Describes the forming of a bond between monomers with the removal of a water molecule.
    a. Hydrolysis
    b. Dehydration

9. Describes the breaking of a bond within a polymer using water.
    a. Hydrolysis
    b. Dehydration

10. Which of the following is NOT in the monomer of a nucleic acid?
    a. pentose sugar
    b. nitrogenous base
    c. phosphate
    d. amino acid

11. Which of the following is NOT in the monomer of a protein?
    a. Amine Group
    b. R Group
    c. Carboxyl Group
    d. Nitrogenous Base

12. Describe the orientation of the phospholipids in the membrane.
    a. Phospholipids orient in bilayer with hydrophilic heads on exterior
    b. Phospholipids orient in monolayer with hydrophilic head on extracellular
    c. Phospholipids orient in bilayer with hydrophobic tails on exterior
    d. Phospholipids orient in monolayer with hydrophobic tails on extracellular

13. How is DNA/RNA synthesis directionally oriented?
    a. new nucleotides are added to 5' phosphate
    b. new nucleotides are added to 3' phosphate
    c. new nucleotides are added to 5' hydroxyl
    d. new nucleotides are added to 3' hydroxyl

14. What component of the polypeptide is the next amino acid added to forming the peptide bond?
    a. amino group
    b. hydrogen
    c. carboxyl group
    d. R group

15. Which protein involves R group bonding to form the final three-dimensional structure?
    a. primary
    b. secondary
    c. tertiary
    d. quaternary

16. Which protein structure involves the peptide bonds between amino acids?
    a. primary
    b. secondary
    c. tertiary
    d. quaternary

17. DNA and RNA differ on many qualities, which of the following is NOT a difference?
    a. Sugar
    b. Nitrogenous Base
    c. Phosphate Group
    d. Strandedness

Multiple Choice Key

Question	Correct Answer	Topic	Source
1	C. Nonpolar R groups that cannot form hydrogen bonds with water are pushed into the middle of the protein.	1.7	2020 CED #12
2	D. The basic molecular structure is a helix.	N/A	2013 #6
3	D. Dissolving fats	1.1	Self
4	C. Polar covalent bonds in structure	1.1	Self
5	D. Nucleic Acids & Proteins	1.2	Self
6	C. Nucleic Acids	1.2	Self
7	B. Proteins	1.2	Self
8	B. Dehydration	1.3	Self
9	A. Hydrolysis	1.3	Self
10	D. Amino Acid	1.3	Self
11	D. Nitrogenous Base	1.6	Self
12	A. Phospholipids orient in bilayer with hydrophilic heads on exterior	1.5	Self
13	D. new nucleotides are added to 3' hydroxyl	1.6	Self
14	C. carboxyl group	1.7	Self
15	C. tertiary	1.7	Self
16	A. primary	1.7	Self
17	C. Phosphate Group	1.6	Self

Multiple Choice Explanations

Q		Explanation:
1	A	Polar groups are formed from polar covalent bonding (unequal sharing of electrons) which gives the polar groups a partial charge. An ionic bond is the attractive bond between an cation and an anion which result from the loss or gain of an electron.
	B	Polar groups will be attracted to the polar nature of water resulting in the polar groups on the surface of the protein.
	C	**Nonpolar groups are formed from nonpolar covalent bonding (equal sharing of electrons) which results in no partial charge. The absence of the partial charge inhibits the hydrogen bonding with water molecules which are polar.**
	D	Bonding (including covalent) between R groups will allow for covalent bonding (and other bonds). It does not apply to only the nonpolar R groups nor does it explain the location of the polar R groups on surface and nonpolar R groups buried in the middle (as stated in the prompt).
2	A	The images would be unable to show the nitrogenous bases thus unable to determine the ratios
	B	The images would be unable to show the nitrogenous bases thus unable to determine the nucleotide sequence
	C	The images would be unable to show the phosphate versus hydroxyl groups thus unable to determine the directionality (to determine antiparallel)
	D	**The image clearly shows a circular shape with an X through the middle. This demonstrates there are two strands or a double helix (circular shape) with binding in the middle of nitrogenous bases (making the X shape).**
3	A	Cohesion is due to water molecules hydrogen binding to one another
	B	Adhesion is due to water molecules hydrogen binding to other polar molecules
	C	Surface tension of water is due to water molecules hydrogen bonding to one another at the surface
	D	**Dissolving fats involves the water molecules surrounding the fat molecule creating a hydration shell. The fats are nonpolar while the water molecules are polar, which means there are no hydrogen bonds formed between these two.**
4	A	Nonpolar covalent bonds are the result of equally sharing valence electrons. This equal sharing does not result in partial charges that allow for the polar nature of water.
	B	Ionic bonds result from the gain or loss of electrons resulting in opposite charged ions. Water does not have ionic bonds as these come form between metals and nonmetals.
	C	**Polar covalent bonds are the result of unequally sharing valence electrons. This unequal sharing results in partial charges that allow for the polar nature of water.**
	D	Hydrophobic interaction results from nonpolar (hydrophobic) groups associating. Nonpolar bonds result from equal sharing due to a similar electronegativity between the atoms.
5	A	Carbohydrates are made up of only carbon, hydrogen, and oxygen.
	B	Great Job! Proteins do have nitrogen in their amino groups. You didn't read all of the answer choices.
	C	Great Job! Nucleic acids do have nitrogen in their nitrogenous base. You didn't read all of the answer choices.
	D	**Nucleic acids have nitrogen in their nitrogenous bases and proteins have nitrogen in their amino group.**
6	A	Carbohydrates are made up of only carbon, hydrogen, and oxygen.
	B	Proteins are made up of carbon, hydrogen, oxygen, nitrogen, and sulfur.
	C	**Nucleic acids are made up of carbon, hydrogen, oxygen, nitrogen, and phosphorus.**
	D	Fats are made up of carbon, hydrogen, and oxygen.
7	A	Carbohydrates are made up of only carbon, hydrogen, and oxygen.
	B	**Proteins are made up of carbon, hydrogen, oxygen, nitrogen, and sulfur.**
	C	Nucleic acids are made up of carbon, hydrogen, oxygen, nitrogen, and phosphorus.

	D	Fats are made up of carbon, hydrogen, and oxygen.
8	A	Hydrolysis involves breaking a water molecule to break a bond between monomers of a polymer.
	B	**Dehydration involves forming a water molecule and forming a bond between monomers of a polymer. The hydroxyl group combines with the hydrogen resulting in the water molecule that is removed.**
9	A	**Hydrolysis involves breaking a water molecule to break a bond between monomers of a polymer.**
	B	Dehydration involves forming a water molecule and forming a bond between monomers of a polymer. The hydroxyl group combines with the hydrogen resulting in the water molecule that is removed.
10	A	Pentose sugar is in nucleotides. DNA has a deoxyribose. RNA has a ribose.
	B	Nitrogenous bases are in nucleotides. DNA has A, T, C, & G. RNA has A, U, C, & G.
	C	Phosphates are in ALL nucleotides.
	D	**Amino acids are the monomer for proteins and not found in the nucleotide monomer.**
11	A	Amine group is in an amino acid. It makes up the N-terminus of the protein.
	B	R group is the variable group found in all amino acids.
	C	Carboxyl group is in an amino acid. It makes up the C-terminus of the protein.
	D	**Nitrogenous bases are found in the nucleotide monomer of nucleic acids. This is not found in the amino acid monomer.**
12	A	**Phospholipids are composed of a polar phosphate group and two nonpolar fatty acid tails. Since the phosphates are polar, there will be bilayer with these polar groups facing the aqueous intracellular and extracellular region.**
	B	Phospholipids will not orient into a monolayer since the intracellular and extracellular areas are both aqueous, so the nonpolar fatty acids need to associate together in the interior.
	C	Phospholipids will orient into a bilayer, but the fatty acids tails are hydrophobic. The tails will associate to the interior of the membrane to avoid the water/polar substances.
	D	Phospholipids will not orient into a monolayer since the intracellular and extracellular areas are both aqueous, so the nonpolar fatty acids need to associate together in the interior.
13	A	DNA/RNA is synthesized in the 5’ to 3’ direction. At the 5’ end, there is a phosphate. Since it is synthesized 5’ to 3’, the new nucleotides will be added to a 3’ end not a 5’ end.
	B	DNA/RNA is synthesized in the 5’ to 3’ direction. At the 3’ end, there is a hydroxyl group. Since it is synthesized 5’ to 3’, the new nucleotides will be added to a 3’ hydroxyl group.
	C	DNA/RNA is synthesized in the 5’ to 3’ direction. At the 5’ end, there is a phosphate. Since it is synthesized 5’ to 3’, the new nucleotides will be added to a 3’ end not a 5’ end.
	D	**DNA/RNA is synthesized in the 5’ to 3’ direction. At the 3’ end, there is a hydroxyl group. Since it is synthesized 5’ to 3’, the new nucleotides will be added to a 3’ hydroxyl group.**
14	A	A peptide bond forms between the carboxyl group of one amino acid and the amine group of the next amino acid. The amine group is the NEXT amino acid.
	B	A peptide bond forms between the carboxyl group of one amino acid and the amine group of the next amino acid. The hydrogen group is not involved in the peptide bond. The hydrogen group is involved in the hydrogen bonding in the secondary structure.
	C	**A peptide bond forms between the carboxyl group of one amino acid and the amine group of the next amino acid.**
	D	A peptide bond forms between the carboxyl group of one amino acid and the amine group of the next amino acid. The R group is not involved in the peptide bond. The R group is involved in the bonding in the tertiary and quaternary structure.
15	A	Primary structure is the “string of amino acids” which involves the peptide bonds between amino acids
	B	Secondary structure is the alpha helix and beta pleated sheets which involves the hydrogen bonding between the polypeptide backbone.
	C	**Tertiary structure is the final three-dimensional structure which involves the R groups bonding**
	D	Quaternary structure is the final three-dimensional structure with multiple polypeptides

16	A	**Primary structure is the "string of amino acids" which involves the peptide bonds between amino acids**
	B	Secondary structure is the alpha helix and beta pleated sheets which involves the hydrogen bonding between the polypeptide backbone.
	C	Tertiary structure is the final three-dimensional structure which involves the R groups bonding
	D	Quaternary structure is the final three-dimensional structure with multiple polypeptides
17	A	DNA has deoxyribose and RNA has ribose for their pentose sugar.
	B	DNA has thymine while RNA has uracil. The other three nitrogenous bases are the same (adenine, cytosine, and guanine)
	C	**Both DNA and RNA have a phosphate group.**
	D	DNA is traditionally a double stranded molecule while RNA is traditionally a single stranded molecule.

Free Response Practice

2025 #2
This question is found in Unit 4.

2024 #2
This question is in Unit 3.

2023 #1
This question is in Unit 4.

2022 #2
This question is in Unit 5.

2021 #2
This question is in Unit 6.

Free Response Scoring Guidelines

Unit 2: Cell Structure and Function

Topic	Learning Objective(s)
2.1 Cell Structure and Function	**2.1.A:** Explain how the structure and function of subcellular components and organelles contribute to the function of cells.
2.2 Cell Size	**2.2.A:** Explain the effect of surface area-to volume ratios on the exchange of materials between cells or organisms and the environment.
2.3 Plasma Membrane	**2.3.A:** Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell. **2.3.B:** Describe the fluid mosaic model of cell membranes.
2.4 Membrane Permeability	**2.4.A:** Explain how the structure of biological membranes influences selective permeability **2.4.B:** Describe the role of the cell wall in maintaining cell structure and function.
2.5 Membrane Transport	**2.5.A:** Describe the mechanisms that organisms use to maintain solute and water balance. **2.5.B:** Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.
2.6 Facilitated Diffusion	**2.6.A:** Explain how the structure of a molecule affects its ability to pass through the plasma membrane.
2.7 Tonicity and Osmoregulation	**2.7.A:** Explain how concentration gradients affect the movement of molecules across membranes. **2.7.B:** Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.
2.8 Mechanisms of Transport	**2.8.A:** Describe the processes that allow ions and other molecules to move across membranes.
2.9 Cell Compartmentalization	**2.9.A:** Describe the membrane-bound structures of the eukaryotic cell. **2.9.B:** Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.
2.10 Origins of Cell Compartmentalization	**2.10.A:** Describe the membrane-bound structures of the eukaryotic cell.

Additional Resources

Unit 2 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

Topic 2.1: Cell Structure and Function

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.1: Ribosomes are comprised of ribosomal RNA (rRNA) and protein. These non-membrane, subcellular structures are found in cells in all forms of life and reflect the common ancestry in all known life. Ribosomes synthesize proteins according to messenger RNA (mRNA) sequences.	☐ I can identify the components of ribosomes. ☐ I can identify the life forms with ribosomes. ☐ I can describe how ribosomes demonstrate common ancestry. ☐ I can describe the function of ribosomes.

1. What are the components of a ribosome?
2. What are the three types of RNA involved in the structure or function of the ribosome?
3. What life forms have ribosomes?
4. What is the structure and function of the ribosome?
5. How does the structure of the ribosome aid in the function?
6. How does the structure of the ribosome aid in the function?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.2: The endomembrane system consists of a group of membrane-bound organelles and subcellular components (endoplasmic reticulum (ER), Golgi complex, lysosomes, vacuoles and transport vesicles, the nuclear envelope, and the plasma membrane) that work together to modify, package, and transport polysaccharides, lipids, and proteins intercellularly.	☐ I can identify the components of the endomembrane system. ☐ I can describe the function of the endomembrane system.

7. What are the components of the endomembrane system?
8. What is the function of the endomembrane system?
9. How does the function of each of the components of the endomembrane system lead to the function of the endomembrane system?

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.</td></tr>
<tr><td>2.1.A.3: Endoplasmic reticulum provides mechanical support by helping cells maintain shape and plays a role in intracellular transport.
i. Rough ER is associated with membrane-bound ribosomes, allows for the compartmentalization of cells, and helps carry out protein synthesis.
ii. Smooth ER functions include the detoxification of cells and lipid synthesis.
☒ Exclusion Statement:
Knowledge of the specific functions of smooth ER in specialized cells is beyond the scope of the AP Exam.</td><td>☐ I can identify the two types of endoplasmic reticulum.
☐ I can describe the function of the endoplasmic reticulum.
☐ I can describe the function of the rough ER.
☐ I can describe the function of the smooth ER.</td></tr>
</table>

10. What are the two types of endoplasmic reticulum?
11. What is the function of the endoplasmic reticulum?
12. How does the endoplasmic reticulum provide mechanical support?
13. How does the endoplasmic reticulum play a role in intracellular transport?
14. Rough Endoplasmic Reticulum
    a. What is the structure and function of the rough ER?
    b. How does the structure of the rough ER aid in the function?
15. What is the relationship between the ribosome and the rough ER?
16. Smooth Endoplasmic Reticulum
    a. What is the structure and function of the smooth ER?
    b. How does the structure of the smooth ER aid in the function?

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.</td></tr>
<tr><td>2.1.A.4: The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs. Functions of the Golgi include:
i. Correctly folding and chemically modifying newly synthesized cellular products
ii. Packaging proteins for trafficking
☒ Exclusion Statement:</td><td>☐ I can describe the structure of the Golgi complex.
☐ I can describe the function of the Golgi complex.</td></tr>
</table>

Knowledge of the role of Golgi in the synthesis of specific phospholipids and packaging of specific enzymes for lysosomes, peroxisomes, and secretory vesicles is beyond the scope of the AP Exam.	

17. What are the three possible names for Golgi?
    - Note: any of the names could appear on the exam so be knowledgeable about the different ways you might see this structure
18. What is the structure and function of the Golgi?
19. How does the structure of the Golgi aid in the function?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.5: Mitochondria have a double membrane that provides compartments for different metabolic reactions involved in aerobic cellular respiration. The outer membrane is smooth, while the inner membrane is highly convoluted, forming folds that enable ATP to be synthesized more efficiently.	☐ I can describe the structure of the mitochondria. ☐ I can describe the function of the mitochondria. ☐ I can describe how the structure of the mitochondria aids in the function.

20. What is the structure and function of the mitochondria?
    - Note: Mitochondria is the "powerhouse of the cell" is not an appropriate response on the AP exam
21. How does the structure of the mitochondria aid in the function?
22. What is the structure of the inner membrane (cristae) of the mitochondria?
    a. How does that contribute to the function of the inner membrane (cristae) of the mitochondria?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.6: Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes that digest material. Lysosomes also play a role in programmed cell death (apoptosis).	☐ I can describe the structure of the lysosome. ☐ I can describe the function of the lysosome.

23. What is the structure and function of the lysosome?
24. How does the structure of the lysosome aid in the function?
25. What is apoptosis?
    a. What role does a lysosome have in apoptosis?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.7: Vacuoles are membrane-bound sacs that play many different roles. i. In plant cells, a specialized large vacuole maintains turgor pressure through nutrient and water storage. ii. In animal cells, vacuoles are smaller in size, are more plentiful than in plant cells, and store cellular materials.	☐ I can describe the structure of vacuoles. ☐ I can describe the functions of vacuoles in plants. ☐ I can describe the function of vacuoles in animals.

26. What is the structure of the vacuole?
27. Which vacuoles are found in a plant cell?
28. Which vacuoles are found in an animal cell?
29. What is the function of the food vacuole?
30. What is the function of the central vacuole?
31. How does the vacuole provide turgor pressure?
32. What is the function of the contractile vacuole?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	
2.1.A.8: Chloroplasts are specialized organelles that are found in plants and photosynthetic algae. Chloroplasts contain a double membrane and serve as the location for photosynthesis.	☐ I can identify organisms with chloroplasts. ☐ I can describe the structure of the chloroplast. ☐ I can describe the function of the chloroplast.

33. What organisms have chloroplasts?
34. What is the structure and function of a chloroplast?
35. How does the structure of the chloroplast aid in the function?

Topic 2.2: Cell Size

Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

2.2.A: Explain the effect of surface area-to volume ratios on the exchange of materials between cells or organisms and the environment.

2.A.1: Surface area-to-volume ratios affect the ability of a biological system to obtain necessary nutrients, eliminate waste products, acquire or dissipate thermal energy, and otherwise exchange chemicals and energy with the environment.

☐ I can explain the effect of surface area to volume ratios on the interactions between cells and the environment.
☐ I can explain the effect of surface area to volume ratios on the interactions between organisms and the environment.
☐ I can calculate the surface area, volume, and SA/V ratio of a sphere.
☐ I can calculate the surface area, volume, and SA/V ratio of a rectangular solid.
☐ I can calculate the surface area, volume, and SA/V ratio of a cylinder.
☐ I can calculate the surface area, volume, and SA/V ratio of a cube.

Surface Area and Volume

Surface Area of a Sphere
$SA = 4\pi r^2$

Volume of a Sphere
$V = \frac{4}{3}\pi r^3$

Surface Area of a Rectangular Solid
$SA = 2lh + 2lw + 2wh$

Volume of a Rectangular Solid
$V = lwh$

Surface Area of a Cylinder
$SA = 2\pi rh + 2\pi r^2$

Volume of a Cylinder
$V = \pi r^2 h$

Surface Area of a Cube
$SA = 6s^2$

Volume of a Cube
$V = s^3$

r = radius
l = length
h = height
w = width
s = length of one side of a cube
SA = surface area
V = volume

1. What is the effect of surface area to volume ratios on interactions between cells and the environment?
2. What type of surface area to volume ratio is most favorable for cells?
3. What is the effect of surface area to volume ratios on interactions between organisms and the environment?
4. Calculate the surface areas for the following “cells”:

Shape of “cell”	Surface Area
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

5. Calculate the volumes for the following "cells":

Shape of "cell"	Volume
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

6. Calculate the surface area to volume ratio for the following "cells"

Shape of "cell"	Surface Area/Volume Ratio
Sphere with a radius of 2	
Cube with a side length of 3	
Rectangular solid with dimensions of 2 x 3 x 4	
Cylinder with a radius of 2 and height of 4	

7. Which "cell" from question #5 would be the most efficient? Justify.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.2.A: Explain the effect of surface area-to volume ratios on the exchange of materials between cells or organisms and the environment.	
2.2.A.2: The surface area of the plasma membrane must be large enough to adequately exchange materials. i. The surface area-to-volume ratio can restrict cell size and shape. Smaller cells typically have a higher surface area-to-volume ratio as well as a more efficient exchange of materials with the environment than do larger cells. ii. As cells increase in volume, the surface area-to-volume ratio decreases and the demand for internal resources increases. iii. More complex cellular structures (e.g., membrane folds) are necessary to adequately exchange materials with the environment. iv. As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the environment. Smaller amounts of mass exchange proportionally more heat with the ambient environment than do larger masses. As mass increases, both the surface area-to-volume ratio and the rate of heat exchange decrease.	☐ I can describe the effect of increasing surface area to volume ratios to cells. ☐ I can identify more efficient cells based on surface area to volume ratios. ☐ I can describe the effect of increasing surface area has on the volume of a cell. ☐ I can explain the function of complex cellular structures in cells. ☐ I can describe the effect of organisms increasing in size on the surface area to volume ratio and its effect of heat exchange. ☐ I can describe how organism size/mass affects rate of heat exchange. ☐ I can describe the relationship between metabolic rate per unit body mass and the size of multicellular organisms.

v. There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms; typically, the smaller the organism, the higher the metabolic rate per unit body mass.	

8. How does an increase of surface area affect the increase in volume?
9. How can a cell increase surface area without increasing the volume?
10. How does an increase in surface area to volume ratio affects the cell?
11. Which cell is the most efficient? Justify.

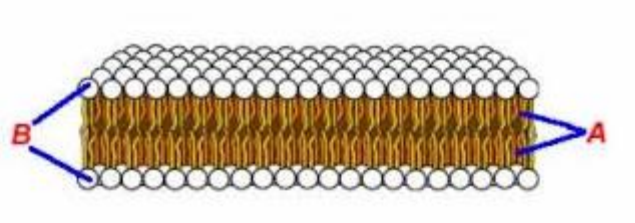
	Surface Area	Volume
Cell A	4 μm^2	3 μm^3
Cell B	8 μm^2	6 μm^3
Cell C	12 μm^2	9 μm^3
Cell D	16 μm^2	12 μm^3

12. What is the function of complex cellular structures like membrane folds on cells?
13. How can an increase in surface area to volume affect heat exchange?
14. What is the relationship between organism size/mass and the rate of heat exchange?
15. Describe the relationship between metabolic rate per unit body mass and the size of the multicellular organisms.

Topic 2.3: Plasma Membrane

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.3.A: Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.	
2.3.A.1: Phospholipids have both hydrophilic and hydrophobic regions. The polar hydrophilic phosphate regions of the phospholipids are oriented toward the aqueous external or internal environment, while the nonpolar hydrophobic fatty acid regions face each other within the interior of the membrane.	☐ I can describe the structure of a phospholipid. ☐ I can describe the polarity of a phospholipid. ☐ I can describe the orientation of phospholipids in a membrane.

1. What are the components of the cell membrane?
2. How do each of the above components function in the cell membrane?
3. On the following diagram of the phospholipid bilayer, label the polar/hydrophilic region and the nonpolar/hydrophobic region.



4. Describe the orientation of the components for the structure of the phospholipid.
5. Based on the following internal and external conditions of the cell, how would the phospholipid molecules be oriented? (Note: aqueous means that it contains water)

Internal conditions	External condition	Describe or draw the orientation of the phospholipid molecule(s)
Aqueous	Aqueous	
Nonaqueous	Aqueous	
Aqueous	Nonaqueous	
Nonaqueous	Nonaqueous	

6. How does the phospholipid bilayer maintain the internal environment of a cell?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.3.A: Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell.	
2.3.A.2: Embedded proteins can be hydrophilic (with charged and polar side groups), hydrophobic (with nonpolar side groups), or both. i. Hydrophilic regions of the proteins are either inside the interior of the protein or exposed to the cytosol (cytoplasm). ii. Hydrophobic regions of proteins make up the protein surface that interacts with the fatty acids in the interior membrane.	☐ I can describe what makes a protein hydrophilic. ☐ I can describe what makes a protein hydrophobic. ☐ I can explain embedded protein location based on a region of the protein.

7. What are the different types of membrane proteins?
8. Describe six functions of membrane proteins.
9. What makes a protein hydrophilic or hydrophobic?
10. How does the polarity of the membrane protein affect its orientation in the membrane?
    a. Where would you find hydrophilic regions of the proteins?
    b. Where would you find hydrophobic regions of the proteins?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.3.B: Describe the fluid mosaic model of cell membranes.	
2.3.B.1: Plasma membranes consist of a structural framework of phospholipid molecules embedded with proteins, steroids (such as cholesterol in vertebrate animals), glycoproteins, and glycolipids. All of these can move around the surface of the cell within the membrane, as illustrated by the fluid mosaic model.	☐ I can describe the structural framework on the plasma membrane. ☐ I can describe the fluid mosaic model.

11. What are the components that make up the plasma membrane?
12. What is the function of steroids in the plasma membrane?
13. What is the function of glycoproteins in the plasma membrane?
14. What is the function of glycolipids in the plasma membrane?
15. Define the fluid mosaic model.

Topic 2.4: Membrane Permeability

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.4.A: Explain how the structure of biological membranes influences selective permeability</td></tr>
<tr><td>2.4.A.1: Plasma membranes separate the internal environment of the cell from the external environment. Selective permeability is the result of the plasma membrane having a hydrophobic interior.</td><td>☐ I can describe the function of plasma membranes.
☐ I can explain why plasma membrane is a selective permeable barrier.</td></tr>
</table>

1. What is the function of the plasma membrane?
2. Describe the composition of the plasma membrane.
3. Why is the plasma membrane a selectively permeable barrier?

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.4.A: Explain how the structure of biological membranes influences selective permeability</td></tr>
<tr><td>2.4.A.2: Small nonpolar molecules, including N_2, O_2, and CO_2, freely pass across the membrane. Hydrophilic substances, such as large polar molecules and ions, move across the membrane through embedded channels and transport proteins.</td><td>☐ I can identify molecules that can pass freely across the plasma membrane.
☐ I can identify molecules that require embedded channels and transport proteins to cross the plasma membrane.
☐ I can describe how polarity of molecules affects path across the plasma membrane.</td></tr>
</table>

4. What types of materials can easily pass through the membrane?
    a. Identify two examples.
    b. Why does this type of material easily pass through the membrane?
5. How do large amounts of water pass through the membrane?
6. What is an embedded transport protein?
    a. Describe the two types of transport proteins.
7. What types of materials require an embedded channel or transport protein to pass through the membrane?
    a. Identify two examples.
    b. Why does this type of material require a protein to pass through the membrane?
8. True or False? Any molecule can use any transport protein.
9. How does the polarity of molecules affect its path across the plasma membrane.
10. What types of materials require a vesicle for export or a food vacuole for import?
    a. Identify two examples.
    b. Why does this type of material require bulk transport?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.4.A: Explain how the structure of biological membranes influences selective permeability	
2.4.A.3: The nonpolar hydrocarbon tails of phospholipids prevent the movement of ions and polar molecules across the membrane. Small polar, uncharged molecules, like H_2O or NH_3 (ammonia), pass through the membrane in small amounts.	☐ I can describe why the plasma membrane inhibits the movement of ions and polar molecules. ☐ I can describe how some small, polar uncharged molecules can pass through the membrane in small amounts.

11. Describe how the plasma membrane inhibits the movement of ions and polar molecules.
12. Describe how ions and polar molecules are able to enter or exit the cell.
13. TRUE or FALSE: Water is able to pass through the membrane in small amounts.
14. How do some small, polar uncharged molecules pass through the membrane in small amounts.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.4.B: Describe the role of the cell wall in maintaining cell structure and function.	
2.4.B.1: Cell walls of Bacteria, Archaea, Fungi, and plants provide a structural boundary as well as a permeability barrier for some substances to the internal or external cellular environments and protection from osmotic lysis.	☐ I can describe the roles of cell walls.

15. What types of cells have a cell wall?
16. How does the cell wall maintain cell structure?
17. How does the cell wall protect the cell from hypotonic solutions?
18. How do materials pass through the cell wall?
19. How does the cell wall of a plant, fungi, and prokaryote differ?

Topic 2.5: Membrane Transport

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.5.A: Describe the mechanisms that organisms use to maintain solute and water balance.	
2.5.A.1: The selective permeability of membranes allows for the formation of concentration gradients of solutes across the membrane.	☐ I can describe a concentration gradient. ☐ I can describe how concentration gradients are formed across the membrane.

1. What is a concentration gradient?
2. How is a concentration gradient maintained?
3. How are concentration gradients formed across the membrane?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.5.A: Describe the mechanisms that organisms use to maintain solute and water balance.	
2.5.A.2: Passive transport is the net movement of molecules from regions of high concentration to regions of low concentration without the direct input of metabolic energy.	☐ I can describe passive transport.

4. What is passive transport?
5. Identify two examples of passive transport.
6. Describe the direction of movement during passive transport.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.5.A: Describe the mechanisms that organisms use to maintain solute and water balance.	
2.5.A.3: Active transport requires the direct input of energy to move molecules. In some cases, active transport is utilized to move molecules from regions of low concentration to regions of high concentration.	☐ I can describe active transport.

7. What is active transport?
8. Identify two examples of active transport.
9. Describe the direction of movement during action transport.

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">2.5.B: Describe the mechanisms that organisms use to transport large molecules across the plasma membrane.</td></tr>
<tr><td>2.5.B.1: The processes of endocytosis and exocytosis require energy to move large substances or large amounts of substances into and out of cells.
i. In endocytosis, the cell takes in large molecules and particulate matter by folding the plasma membrane in on itself and forming new (small) vesicles that engulf material from the external environment.
ii. In exocytosis, internal vesicles release material from cells by fusing with the plasma membrane and secreting large molecules from the cell.</td><td>☐ I can describe the process of endocytosis.
☐ I can describe the process of exocytosis.</td></tr>
</table>

10. Describe the process of endocytosis.
11. Describe three types of endocytosis.
12. TRUE or FALSE: The processes of endocytosis and exocytosis are forms of active transport.
13. Identify an example of a material that would require endocytosis.
14. How are the food materials brought in by endocytosis digested?
15. What is exocytosis?
16. Identify an example of a material that would require exocytosis.

Topic 2.6: Facilitated Diffusion

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane.</td></tr>
<tr><td>2.6.A.1: Facilitated diffusion requires transport or channel proteins to enable the movement of charged ions across the membrane.
i. Membranes may become polarized by the movement of ions across the membrane.
ii. Charged ions, including Na^+ (sodium) and K^+ (potassium), require channel proteins to move through the membrane.</td><td>☐ I can describe facilitated diffusion.
☐ I can explain how charged ions move across the membrane.
☐ I can describe the effect of charged ions moving across the membrane.</td></tr>
</table>

1. What is facilitated diffusion?
2. TRUE or FALSE: Facilitated diffusion requires a transport or channel protein.
3. How do charged molecules or ions pass through the membrane?
4. Describe how the membrane potential changes as ions move across the membrane.

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane.</td></tr>
<tr><td>2.6.A.2: Facilitated diffusion enables the movement of large polar molecules through membranes with no energy input. In this type of diffusion, substances move down the concentration gradient.</td><td>☐ I can explain how large polar molecules across the membrane.</td></tr>
</table>

5. How are large polar molecules able to move across the plasma membrane?
    a. What type of transport is involved with the movement of large polar molecules across the plasma membrane?

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane.</td></tr>
<tr><td>2.6.A.3: Aquaporins transport large quantities of water across membranes.</td><td>☐ I can describe aquaporins.
☐ I can explain how large quantities of water move across the membrane.</td></tr>
</table>

6. What are aquaporins?
7. How are large quantities of water moved across the membrane?

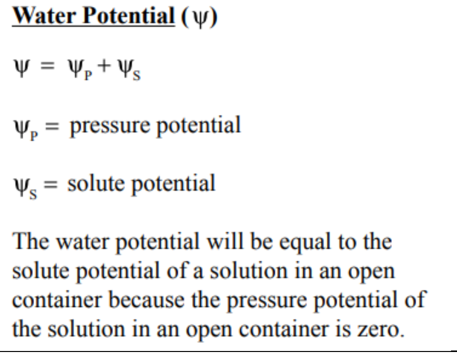
Topic 2.7: Tonicity and Osmoregulation

Energetics:

Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

2.7.A: Explain how concentration gradients affect the movement of molecules across membranes.

2.7.A.1: External environments can be hypotonic, hypertonic, or isotonic to internal environments of cells. Movement of water can also be described as moving from hypotonic to hypertonic regions. Water moves by osmosis from regions of high water potential to regions of low water potential.	☐ I can determine the tonicity of a solution/external environment. ☐ I can describe water movement based on tonicity of a solution/external environment. ☐ I can calculate the water potential of a solution. ☐ I can describe water movement based on water potential of a solution/external environment.



Water Potential (ψ)

$\psi = \psi_P + \psi_S$

ψ_P = pressure potential

ψ_S = solute potential

The water potential will be equal to the solute potential of a solution in an open container because the pressure potential of the solution in an open container is zero.

1. What does it mean if a solution is hypotonic?
2. What does it mean if a solution is hypertonic?
3. What does it mean if a solution is isotonic?
4. Using the following chart, determine which direction the water will flow and the result to the cell.

Intracellular Environment	Extracellular Environment	Direction of Water Flow	Result to the Cell
Hypotonic	Hypertonic		
Isotonic	Isotonic		
Hypertonic	Hypotonic		
0.75 M	0.5 M		
0.25 M	0.25 M		
0.5 M	0.75 M		

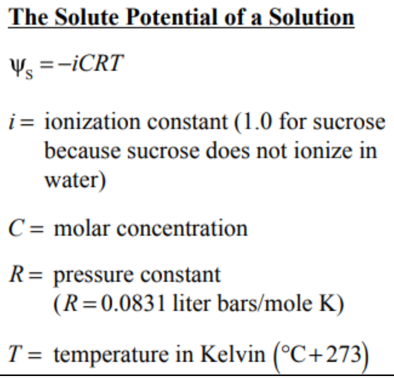
5. What is water potential?
6. How does it explain the direction of water movement?
7. Calculate the water potential of the following solutions.

Cell	Ψ_P	Ψ_S	Ψ
A	0.0 MPa	-0.2 MPa	
B	0.8 MPa	-0.4 MPa	

8. Which direction will water flow based on the information in question 7? Justify.

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.7.B: Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.</td></tr>
<tr><td>2.7.B.1: Growth and homeostasis are maintained by the constant movement of molecules across membranes.</td><td>☐ I can describe how growth and homeostasis are maintained.</td></tr>
</table>

9. What is homeostasis?
10. How does movement of molecules across membranes maintain homeostasis and growth?

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.7.B: Explain how osmoregulatory mechanisms contribute to the health and survival of organisms.</td></tr>
<tr><td>2.7.B.2: Osmoregulation maintains water balance and allows organisms to control their internal solute composition and water potential. Water moves from regions of low osmolarity or solute concentration to regions of high osmolarity or solute concentration.</td><td>☐ I can describe osmoregulation.
☐ I can calculate solute potential of a solution.
☐ I can determine water movement based on the osmolarity of two solutions.
☐ I can determine water movement based on the solute concentration of two solutions.
☐ I can explain how organisms use osmoregulation to maintain water balance and control internal solute composition.</td></tr>
<tr><td colspan="2">
The Solute Potential of a Solution
$\psi_s = -iCRT$
i = ionization constant (1.0 for sucrose because sucrose does not ionize in water)
C = molar concentration
R = pressure constant ($R = 0.0831$ liter bars/mole K)
T = temperature in Kelvin ($°C + 273$)</td></tr>
</table>

11. What is osmoregulation?
12. Identify two ways that the cell complete osmoregulation.
13. Identify two ways that organisms complete osmoregulation.
14. Which direction would water flow if one solution A is 0.5 M and solution B is 0.2 M?
15. Which direction would water flow if one solution A is 0.3 M and solution B is 0.6 M?
16. Calculate the solute potential of the following sucrose solutions at 25 degrees Celsius.

Solution	i	C	R	T	Ψ_s
Intracellular		0.5 M			
Extracellular		0.2 M			

17. Assuming a pressure potential of 0.0 MPa, which direction will water flow based on the information provided in question 15? Justify.

18. Calculate the solute potential of the following NaCl solutions at 27 degrees Celsius.

Solution	i	C	R	T	Ψ_s
Intracellular		0.3 M			
Extracellular		0.6 M			

19. Assuming a pressure potential of 0.0 MPa, which direction will water flow based on the information provided in question 17? Justify.
20. How do organisms use osmoregulation to maintain water balance?
21. How do organisms use osmoregulation to control the internal solute composition?

Topic 2.8: Mechanisms of Transport

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">2.8.A: Describe the processes that allow ions and other molecules to move across membranes.</td></tr>
<tr><td>2.8.A.1: Metabolic energy (such as that from ATP) is required for active transport of molecules and ions across the membrane and to establish and maintain electrochemical gradients.
i. Membrane proteins are necessary for active transport.
ii. The Na+/K+ pump and ATPase contribute to the maintenance of the membrane potential</td><td>☐ I can describe how to establish and maintain electrochemical gradients
☐ I can identify necessary components for active transport
☐ I can identify two transport proteins that maintain the membrane potential
☐ I can describe the function of a Na+/K+ pump or ATPase</td></tr>
</table>

1. What is an electrochemical gradient?
2. What are the two components of an electrochemical gradient?
3. Describe how to establish and maintain an electrochemical gradient.
4. Describe the process of active transport.
5. What are the necessary components for active transport?
6. Identify two transport proteins that maintain membrane potential.
7. How does a Na^+/K^+ pump maintain the membrane potential?
    a. What is the function of Na^+/K^+?
8. How does an ATPase contribute to the maintenance of the membrane potential?
    a. What is the function of ATPase?

Topic 2.9: Cell Compartmentalization

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.9.A: Describe the membrane-bound structures of the eukaryotic cell.	
2.9.A.1: Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions.	☐ I can describe how membranes and membrane-bound organelles allow for compartmentalization. ☐ I can identify membrane-bound organelles.

1. Describe how membranes allow for compartmentalization.
2. How does the membrane of organelles allow for specific processes to take place?
    a. Identify two examples of processes that could not take place without the use of a membrane.
3. How do membrane-bound organelles allow for compartmentalization of the cell and its functions?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
2.9.B: Explain how internal membranes and membrane-bound organelles contribute to compartmentalization of eukaryotic cell functions.	
2.9.B.1: Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing the surface area where reactions can occur.	☐ I can describe how internal membrane facilitate cellular processes. ☐ I can describe the effect of an increased surface area where reactions occur.

4. Describe how internal membrane facilitate cellular processes.
5. What is the function of the inner membrane folding in the mitochondria?
6. What is the function of the endoplasmic reticulum's folded membrane?
7. What is the function of thylakoid membranes in the chloroplast?
8. What is the function of the multiple membranes and sacs found in the Golgi?
9. Describe the effect of an increased surface area where reactions occur.

Topic 2.10: Origins of Cell Compartmentalization

Evolution: The process of evolution drives the diversity and unity of life.	
2.10.A: Describe the membrane-bound structures of the eukaryotic cell.	
2.10.A.1: Membrane-bound organelles such as mitochondria and chloroplasts evolved from once free-living prokaryotic cells via endosymbiosis.	☐ I can describe endosymbiosis. ☐ I can identify two membrane-bound organelles that resulted from endosymbiosis. ☐ I can describe how some membrane-bound organelles evolved from once free-living prokaryotic cells.

1. What is endosymbiosis?
2. Describe endosymbiosis.
3. Identify two membrane-bounded organelles that resulted from endosymbiosis.
4. What is the endosymbiotic theory?
5. How did the mitochondria and chloroplast evolve from once free-living prokaryotic cells?
6. How did membrane bound organelles originate in eukaryotic cells?

Evolution: The process of evolution drives the diversity and unity of life.	
2.10.A: Describe the membrane-bound structures of the eukaryotic cell.	
2.10.A.2: Prokaryotes typically lack internal membrane-bound organelles but have internal regions with specialized structures and functions.	☐ I can describe the differences between eukaryotic and prokaryotic cells. ☐ I can describe prokaryotic internal regions with specialized structures and functions.

7. What are prokaryotes?
8. Identify three similarities between a prokaryotic and eukaryotic cell.
9. Identify three differences between a prokaryotic and eukaryotic cell.
10. How is a prokaryotic cell compartmentalized?
11. Describe prokaryotic internal regions with specialized structures and functions.

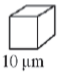
Evolution: The process of evolution drives the diversity and unity of life.	
2.10.A: Describe the membrane-bound structures of the eukaryotic cell.	
2.10.A.3: Eukaryotic cells maintain internal membranes that partition the cell into specialized regions.	☐ I can describe how eukaryotic cells maintain internal membranes. ☐ I can describe the function of eukaryotic internal membranes.

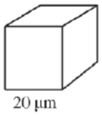
12. Describe how eukaryotic cells maintain internal membranes.
13. What is the function of the inner membrane folding in the mitochondria?
14. What is the function of the endoplasmic reticulum's folded membrane?

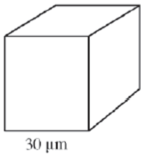
15. What is the function of thylakoid membranes in the chloroplast?
16. What is the function of the multiple membranes and sacs found in the Golgi?
17. Describe the function of eukaryotic internal membranes.

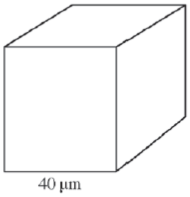
Multiple Choice Practice

1. Simple cuboidal epithelial cells line the ducts of certain human exocrine glands. Various materials are transported into or out of the cells by diffusion. (The formula for the surface area of a cube is $6 \times S^2$, and the formula for the volume of a cube is S^3, where S = the length of a side of the cube.) Which of the following cube-shaped cells would be most efficient in removing waste by diffusion?

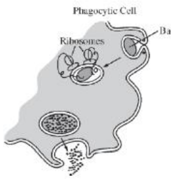
a.


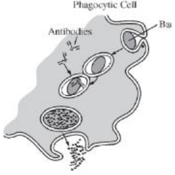
b.


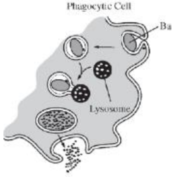
c.


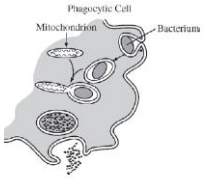
d.


2. A pathogenic bacterium has been engulfed by a phagocytic cell as part of the nonspecific (innate) immune response. Which of the following illustrations best represents the response?

a.


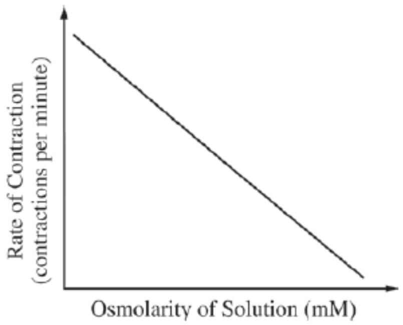
b.


c.


d.


3. If ATP breakdown (hydrolysis) is inhibited, which of the following types of movement across cell membranes is also inhibited?
   a. Movement of oxygen into a cell
   b. Movement of water through aquaporins
   c. Passage of a solute against its concentration gradient
   d. Facilitated diffusion of a permeable substance

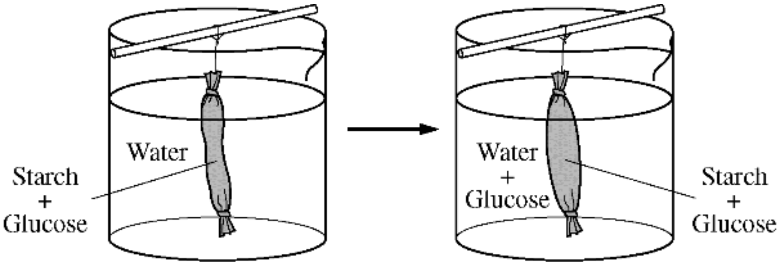
4. A human kidney filters about 200 liters of blood each day. Approximately two liters of liquid and nutrient waste are excreted as urine. The remaining fluid and dissolved substances are reabsorbed and continue to circulate throughout the body. Antidiuretic hormone (ADH) is secreted in response to reduced plasma volume. ADH targets the collecting ducts in the kidney, stimulating the insertion of aquaporins into their plasma membranes and an increased reabsorption of water.
   If ADH secretion is inhibited, which of the following would initially result?
   a. The number of aquaporins would increase in response to the inhibition of ADH.
   b. The person would decrease oral water intake to compensate for the inhibition of ADH.
   c. Blood filtration would increase to compensate for the lack of aquaporins.
   d. The person would produce greater amounts of dilute urine.

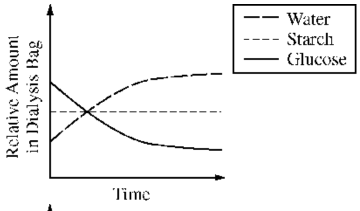


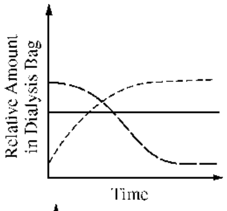
5. Paramecia are unicellular protists that have contractile vacuoles to remove excess intracellular water. In an experimental investigation, paramecia were placed in salt solutions of increasing osmolarity. The rate at which the contractile vacuole contracted to pump out excess water was determined and plotted against osmolarity of the solutions, as shown in the graph. Which of the following is the correct explanation for the data?

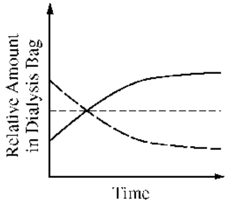
a. At higher osmolarity, lower rates of contraction are required because more salt diffuses into the paramecia.
b. The contraction rate increases as the osmolarity decreases because the amount of water entering the paramecia by osmosis increases.
c. The contractile vacuole is less efficient in solutions of high osmolarity because of the reduced amount of ATP produced from cellular respiration.
d. In an isosmotic salt solution, there is no diffusion of water into or out of the paramecia, so the contraction rate is zero.

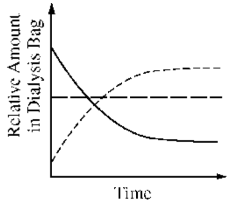
6. A common laboratory investigation involves putting a solution of starch and glucose into a dialysis bag and suspending the bag in a beaker of water, as shown in the figure below.
The investigation is aimed at understanding how molecular size affects movement through a membrane.
Which of the following best represents the amount of starch, water, and glucose in the dialysis bag over the course of the investigation?



a.


c.


b.


d.


7. A student used a microscope to observe a wet-mount slide of red onion epidermal cells that were suspended in a 1% NaCl solution. The student then added a 15% NaCl solution to the slide and observed the changes that occurred. The student's observations are represented in Figure 1. Which of the following most directly explains the changes in the cells?

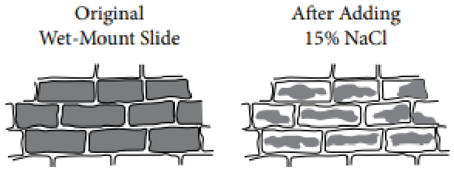


Figure 1. Student's observations of onion cells

a. The degradation of DNA in the nuclei of the cells
b. The lysis of chloroplasts in the cells
c. The movement of water from the central vacuoles of the cells into the solution
d. The movement of NaCl from the solution into the cytoplasm of the cells

8. Describe the difference between rough ER and smooth ER.
    a. Rough ER compartmentalizes cell; Smooth ER functions in detox and lipid synthesis
    b. Rough ER functions in ribosome synthesis; Smooth ER functions in lipid synthesis
    c. Rough ER functions in detox and lipid synthesis; Smooth ER compartmentalizes cell
    d. Rough ER functions in lipid synthesis; Smooth ER functions in ribosome synthesis

9. Which organelle is a membrane-bound structure that functions in correct folding/chemical modification of proteins?
    a. Golgi complex
    b. Lysosome
    c. Mitochondria
    d. Chloroplast

10. Which is membrane-enclosed sacs that contain hydrolytic enzymes?
    a. Golgi complex
    b. Lysosome
    c. Mitochondria
    d. Chloroplast

11. Which is responsible for storage and release of macromolecules and cellular waste products. In plants, aids in turgor.
    a. Endoplasmic Reticulum
    b. Lysosome
    c. Mitochondria
    d. Vacuole

12. Describe the relationship between cell size and SA:V ratios.
    a. As cells increase in size, the SA:V ratio increases
    b. As cells decrease in size, the SA:V ratio decreases
    c. As cells increase in size, the SA:V ratio decreases
    d. Cell size has no effect on the SA:V ratio

13. Describe the characteristics of a membrane-bound protein.
    a. Entire protein is hydrophilic
    b. Entire protein is hydrophobic
    c. Hydrophilic R group exterior cell & hydrophobic R group interior membrane
    d. Hydrophilic R group interior membrane & hydrophobic R group interior cell

14. Identify which of the following will easily pass through the membrane.
    a. Water
    b. Protein Hormone
    c. Steroid Hormone
    d. Charged Ion

15. Identify which of the following will bind to a membrane protein (and will not enter the cell).
    a. Water
    b. Protein Hormone
    c. Steroid Hormone
    d. Charged Ion

16. Which of the following requires an input of energy for membrane transport?
    a. Charged ion moving against concentration gradient
    b. Water moving into a hypertonic cell
    c. Charged ion moving with concentration gradient
    d. Water moving out of a hypotonic cell

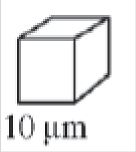
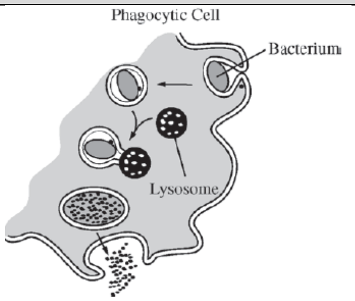
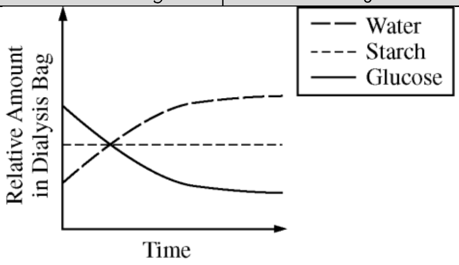
17. What is the difference between endocytosis and exocytosis?
    a. Endocytosis involves cytoplasm of a neighboring cell entering
    b. Endocytosis involves phagocytosis or pinocytosis to bring materials in cell
    c. Exocytosis involves cytoplasm of a neighboring cell exiting
    d. Exocytosis involves phagocytosis or pinocytosis to remove material from cell

18. Which of the following correctly describe the movement of water?
    a. Cell with 0.5M concentration will gain water from the 1.0M exterior solution
    b. Cell with 0.5M concentration will gain water from the 0.5M exterior solution
    c. Cell with 1.0M concentration will gain water from the 0.5M exterior solution
    d. Cell with 0.5M concentration will lose water to the 0.5M exterior solution

19. Why is a eukaryotic cell able to be larger than a prokaryotic cell?
    a. Membrane-bound organelles compartmentalize intracellular processes
    b. Prokaryotic cells have a nucleus which decreases the volume of the cell
    c. Eukaryotic cells have a nucleus which decreases the volume of the cell
    d. Absence of membrane-bound organelles allows for enzymatic reactions.

20. Which of the following best describes the relationship between metabolic rate per unit body mass and the size of multicellular organisms?
    a. the smaller the organism, the higher the metabolic rate
    b. the larger the organism, the higher the metabolic rate
    c. the higher the surface area to volume ratio of the cells, the higher the metabolic rate
    d. the lower the surface area to volume ratio of the cells, the higher the metabolic rate

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	A. 	2.2	2012 CED #2
2	C. 	2.5	2012 CED #5
3	C. Passage of a solute against its concentration gradient	2.8	2013 #3
4	D. The person would produce greater amounts of dilute urine.	2.6	2012 CED #30
5	B. The contraction rate increases as the osmolarity decreases because the amount of water entering the paramecia by osmosis increases.	2.7	2012 CED #12
6	A. 	2.5	2013 #19
7	C. The movement of water from the central vacuoles of the cells into the solution	2.7	2020/2026 CED #10
8	A. Rough ER compartmentalizes cell; Smooth ER functions in detox and lipid synthesis	2.1	Self
9	A. Golgi complex	2.1	Self
10	B. Lysosome	2.1	Self
11	D. Vacuoles	2.1	Self
12	C. As cells increase in size, the SA:V ratio decreases	2.2	Self
13	C. Hydrophilic R group exterior cell & hydrophobic R group interior membrane	2.3	Self
14	C. Steroid Hormone	2.4	Self
15	B. Protein Hormone	2.4	Self
16	A. Charged ion moving against concentration gradient	2.5	Self
17	B. Endocytosis involves phagocytosis or pinocytosis to bring materials in cell	2.5	Self
18	C. Cell with 1.0M concentration will gain water from the 0.5M exterior solution	2.7	Self
19	A. Membrane-bound organelles compartmentalize intracellular processes	2.10	Self
20	A. the smaller the organism, the higher the metabolic rate	2.2	Self

Multiple Choice Explanations

Q		Explanation:
1	A	**You should be able to look at this question to know that the smallest cube will have the largest surface area to volume ratio making it the most efficient at removing waste by diffusion. If you need to do the calculations, compare by using a 1x1x1 cube. Surface Area = 6 and Volume = 1, so SA/V = 6** **This option is correct. It demonstrates the ability to calculate surface area-to-volume ratios and predict their effects on a cell's ability to exchange materials with its environment. The cell shown in A has the greatest surface area-to-volume ratio at 0.6:1. (CollegeBoard)**
	B	You should be able to look at this question to know that the smallest cube (A) will have the largest surface area to volume ratio making it the most efficient at removing waste by diffusion. If you need to do the calculations, compare by using a 2x2x2 cube. Surface Area = 24 and Volume = 8, so SA/V = 3 This option is incorrect. That cell does not have the greatest surface area-to-volume ratio at 0.3:1. (CollegeBoard)
	C	You should be able to look at this question to know that the smallest cube (A) will have the largest surface area to volume ratio making it the most efficient at removing waste by diffusion. If you need to do the calculations, compare by using a 3x3x3 cube. Surface Area = 54 and Volume = 27, so SA/V = 2 This option is incorrect. That cell does not have the greatest surface area-to-volume ratio at 0.2:1. (CollegeBoard)
	D	You should be able to look at this question to know that the smallest cube (A) will have the largest surface area to volume ratio making it the most efficient at removing waste by diffusion. If you need to do the calculations, compare by using a 4x4x4 cube. Surface Area = 96 and Volume = 64, so SA/V = 1.5 This option is incorrect. That cell does not have the greatest surface area-to-volume ratio at 0.1:1. (CollegeBoard)
2	A	Ribosomes have a function to synthesize proteins. The hydrolytic enzymes that will be responsible for hydrolysis of an engulfed bacteria would be synthesized by membrane ribosomes on the rough ER then modified by the Golgi prior to be used in phagocytosis. This option is incorrect. Ribosomes do not play a direct role in phagocytosis, although they are organelles that carry out protein synthesis. (CollegeBoard)
	B	Antibodies are released by plasma cells as a signal for macrophages to engulf. This diagram shows the antibodies inside of the cell being used for digestion. This option is incorrect. Antibodies do not play a role in phagocytosis, a nonspecific immune response. Antibodies are involved in specific immune responses in the presence of specific antigens. Antibodies do not act intracellularly either. (CollegeBoard)
	C	**Lysosomes have hydrolytic enzymes responsible for digestion. Recall, after phagocytosis – the food vacuole formed will fuse with a lysosome for digestion.** **This option is correct. It demonstrates an understanding to interpret representations that describe a nonspecific immune response. In phagocytosis, a cell engulfs a bacterium by wrapping pseudopodia around it and packaging it within a membrane-enclosed vacuole. The bacterium is digested after the vacuole fuses with a lysosome containing hydrolytic enzymes. Digested particles can be exported out of the cell by exocytosis. (CollegeBoard)**
	D	Mitochondria is the site of cellular respiration. This process will not result in digestion of materials.

		This option is incorrect. Mitochondria do not play a direct role in cellular digestion. Mitochondria are the sites of cellular respiration, the metabolic process that generates ATP from organic molecules in the presence of oxygen. (CollegeBoard)
3	A	Oxygen does not require a transport protein since it is small and nonpolar. The ATP breakdown is referring to an active transport situation which uses ATP and a transport protein.
	B	Water requires a transport protein to move large amounts across the membrane. This statement does not demonstrate that it will be going against its concentration gradient to require ATP.
	C	**Active transport involves the usage of a transport protein to move a material against its concentration gradient.**
	D	Facilitated transport is a type of passive transport and does not require ATP.
4	A	ADH stimulates the insertion of aquaporins (increasing the number of aquaporins), but this statement says the ADH is inhibited which means the ADH is unable to do its job. There will not an increase of aquaporins. This option is incorrect. ADH stimulates the production of aquaporins. Inhibition of ADH would result in fewer aquaporins. (CollegeBoard)
	B	ADH stimulates the insertion of aquaporins (increasing the number of aquaporins) which would result in additional water being re-absorbed decreasing the need to consume oral water intake. But if ADH is inhibited, the water isn't reabsorbed thus the person would need to increase their oral water intake to off balance the loss of water. This option is incorrect because inhibition of ADH causes more water to be excreted from the body, thus triggering thirst rather than decreasing it (CollegeBoard)
	C	ADH stimulates the insertion of aquaporins (increasing the number of aquaporins) so since the ADH is inhibited there will not be aquaporins in the membrane to reabsorb the water. This statement refers to blood filtration to increase which is not affected by the ADH as this step precedes the aquaporins. This option is incorrect because filtration of the blood in the kidney is independent of ADH. (CollegeBoard)
	D	**ADH stimulates the insertion of aquaporins which reabsorbs the water back into the blood stream. Without the transport protein to move water back into the blood, the excess water remains in the urine making dilute urine.** **This option is correct because it links the signal (ADH) with the response (reabsorption of water). Because ADH increases reabsorption of water, its lack would result in less water reabsorbed, more excreted, and thus a more dilute urine. (CollegeBoard)**
5	A	Recall that ions required specific transport proteins to move across the membrane. There is no information about those transport proteins, so we are looking just at the water movement across the membrane. As the osmolarity increases, there is more salt in the solution which results in less water diffusing into the paramecium so there is less contractions to pump that excess water back out. This option is incorrect because the paramecium's plasma membrane is not permeable to charged ions, so no salt will enter. If salt could enter the paramecium, then water would follow by osmosis and actually result in increasing contractions of the contractile vacuole. (CollegeBoard)
	B	**The more hypotonic the solution is to the paramecium, the higher the amount of water entering the cell. As the solution gets less hypotonic to the paramecium, the amount of water entering will decrease. When the paramecium is in low osmolarity, there is a high rate of contraction because**

		there is a large amount of water entering. When the paramecium is in high osmolarity, there is a low rate of contraction because there is a small amount of water entering. **This option is correct. The lower the concentration of solute, the larger the gradient between the paramecium and the solution. When the paramecium is hypertonic to the low concentration solution, water will enter the paramecium by osmosis. If the paramecium does not pump excess water back out, it will burst. As the solution gradient decreases, less water will enter, and, therefore, there will be a decreased need to pump excess water out (CollegeBoard)**
	C	There is no information that refers to the ATP and whether there would be a lack of ATP. The higher amount of osmolarity leads to a decrease in contraction as there is less water entering the paramecium to be pumped out. This option is incorrect because the external concentration of salt has no direct relationship with internal ATP production by cellular respiration. As long as the paramecium's internal environment is not altered, then cellular respiration should be unaffected, and therefore the contractile vacuole will have sufficient energy. (CollegeBoard)
	D	An isotonic solution refers to an equal amount of water entering and leaving the cell. This answer choice states that no water movement would take place which does not refer to an isotonic solution. This option is incorrect because even at isosmotic concentrations water still diffuses, but in dynamic equilibrium (CollegeBoard)
6	A	**Use the diagram and determine whether the graph fits. The dotted line is the starch, the starch begins in the bag and remains in the bag (no change in the amount in the bag). The dashed line is the water, the bag begins deflated but appears to be more inflated after representing water movement into the bag (increase in the amount in the bag). The solid line is the glucose, the glucose begins in the bag and is found in the bag and the solution after (decrease in the amount in the bag).**
	B	Use the diagram and determine whether the graph fits. The dotted line is the starch, the starch begins in the bag and remains in the bag (no change in the amount in the bag). The dashed line is the water, the bag begins deflated but appears to be more inflated after representing water movement into the bag (increase in the amount in the bag), but this graph shows a decrease. The solid line is the glucose, the glucose begins in the bag and is found in the bag and the solution after (decrease in the amount in the bag), but this graph shows an increase.
	C	Use the diagram and determine the graph fits. The dotted line is the starch, the starch begins in the bag and remains in the bag (no change in the amount in the bag) but this graph shows an increase. The dashed line is the water, the bag begins deflated but appears to be more inflated after representing water movement into the bag (increase in the amount in the bag) but this graph shows a decrease. The solid line is the glucose, the glucose begins in the bag and is found in the bag and the solution after (decrease in the amount in the bag) but this graph shows no change.
	D	Use the diagram and determine whether the graph fits. The dotted line is the starch, the starch begins in the bag and remains in the bag (no change in the amount in the bag), but this graph shows an increase. The dashed line is the water, the bag begins deflated but appears to be more inflated after representing water movement into the bag (increase in the amount in the bag), but this graph shows no change. The solid line is the glucose, the glucose begins in the bag and is found in the bag and the solution after (decrease in the amount in the bag), but this graph shows a decrease.
7	A	The nucleus is traditionally depicted as a circle in the center of the cell. This diagram is not showing the nucleus so there is no information to justify a degrading of DNA. You can see the cell wall in the figure and see the cell getting smaller, which refers to a loss of water due to a hypertonic solution.
	B	The chloroplasts are not depicted in these cells and thus there is no information to justify a lysis of chloroplasts.

	C	**As the concentration of the NaCl (table salt) increases outside the cell, the solution becomes more hypertonic to the cell resulting in a loss of water which causes plasmolysis (plasma membrane pulls away from the cell wall). This water is stored in the central vacuole.**
	D	NaCl is an ionic compound resulting in a positively charged Na and a negatively charged Cl. These ions require specific transport proteins to move across the membrane. In addition, if NaCl entered the cell there would not demonstrate the loss of volume demonstrated in the diagram.
8	A	**This is directly from the CED. SYI-1.D.3: Endoplasmic reticulum (ER) occurs in two forms—smooth and rough. Rough ER is associated with membrane-bound ribosomes— (a) Rough ER compartmentalizes the cell. (b) Smooth ER functions include detoxification and lipid synthesis**
	B	Ribosomes are synthesized in the nucleolus.
	C	Smooth ER functions in the detox and lipid synthesis and Rough ER compartmentalizes the cell.
	D	Smooth ER functions in lipid synthesis and ribosomes are synthesized in the nucleolus.
9	A	**The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs— Functions of the Golgi include the correct folding and chemical modification of newly synthesized proteins and packaging for protein trafficking. (CED SYI-1.D.4)**
	B	Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes (CED SYI-1.D.6)
	C	Mitochondria is the site of Krebs cycle and oxidative phosphorylation of cellular respiration.
	D	Chloroplast is the site of photosynthesis (light reactions and Calvin cycle).
10	A	The Golgi complex is a membrane-bound structure that consists of a series of flattened membrane sacs— Functions of the Golgi include the correct folding and chemical modification of newly synthesized proteins and packaging for protein trafficking. (CED SYI-1.D.4)
	B	**Lysosomes are membrane-enclosed sacs that contain hydrolytic enzymes (CED SYI-1.D.6)**
	C	Mitochondria is the site of Krebs cycle and oxidative phosphorylation of cellular respiration.
	D	Chloroplast is the site of photosynthesis (light reactions and Calvin cycle).
11	A	Endoplasmic reticulum provides mechanical support, carries out protein synthesis on membrane-bound ribosomes, and plays a role in intracellular transport. (SYI-1.E.1)
	B	Lysosomes contain hydrolytic enzymes, which are important in intracellular digestion, the recycling of a cell's organic materials, and programmed cell death (apoptosis) (SYI-1.E.1)
	C	Mitochondrial double membrane provides compartments for different metabolic reactions. (SYI-1.E.1)
	D	**Vacuoles have many roles, including storage and release of macromolecules and cellular waste products. In plants, it aids in retention of water for turgor pressure. (SYI-1.E.1)**
12	A	As the cell increases in size, the surface area is a squared function and the volume is cubed function leading to the denominator (volume) increasing faster than the numerator (surface area). This causes a smaller SA:V ratio.
	B	As the cell increases in size, the surface area is a squared function and the volume is cubed function leading to the denominator (volume) increasing faster than the numerator (surface area). This causes a smaller SA:V ratio. When the cell decreases in size, it would be the reverse of this so it would cause a larger SA:V ratio.
	C	**As the cell increases in size, the surface area is a squared function and the volume is cubed function leading to the denominator (volume) increasing faster than the numerator (surface area). This causes a smaller SA:V ratio.**
	D	Cell size affects the SA:V ratio. The surface area is a squared function and the volume is cubed function leading to a difference when the cell increases or decreases in size.
13	A	The plasma membrane has a hydrophobic region (interior) and hydrophilic region (exterior). In order for the protein to rest in the hydrophobic region, it must have a hydrophobic region.
	B	The plasma membrane has a hydrophobic region (interior) and hydrophilic region (exterior). In order for the protein to rest in the hydrophilic region, it must have a hydrophilic region.

	C	**The plasma membrane has a hydrophobic region (interior) and hydrophilic region (exterior). The protein must be folded for the hydrophobic R groups to associate with the interior of the membrane and the hydrophilic R groups to associate with the exterior of the membrane.**
	D	The plasma membrane has a hydrophobic region (interior) and hydrophilic region (exterior). The protein must be folded for the hydrophobic R groups to associate with the interior of the membrane and the hydrophilic R groups to associate with the exterior of the membrane.
14	A	Although water is able to slowly move through the membrane, it is a polar molecule and unable to easily pass through the membrane without a transport protein.
	B	Protein hormones are polar. They will bind to a membrane protein to activate a signal transduction pathway and are unable to pass through the plasma membrane.
	C	**Steroid hormones are nonpolar. They will be able to pass through the plasma membrane then bind to an intracellular receptor to activate a signal transduction pathway.**
	D	Charged ions are charged leading to a polar nature inhibiting the charged molecule from passing through the hydrophobic core of the plasma membrane.
15	A	Water is able to slowly diffuse through the membrane, but traditionally uses a transport protein to diffuse across the membrane.
	B	**Protein hormones are polar and unable to cross the membrane. These hormones will bind to a membrane protein to activate a signal transduction pathway.**
	C	Steroid hormones are nonpolar. They will be able to pass through the plasma membrane then bind to an intracellular receptor to activate a signal transduction pathway.
	D	A charged ion is polar and requires a transport protein to cross the plasma membrane.
16	A	**Input of energy (ATP) is required for materials undergoing active transport, against their concentration gradient. When the charged ion moves against its concentration gradient, it requires ATP.**
	B	Water moving into a hypertonic cell involves water moving down its concentration gradient which does not require an input of energy (ATP).
	C	Charged ions moving with their concentration gradient is facilitated transport which does not require an input of energy (ATP).
	D	Water moving out of a hypotonic cell involves water moving down its concentration gradient which does not require an input of energy (ATP).
17	A	In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane. (ENE-2.F.2)
	B	**In endocytosis, the cell takes in macromolecules and particulate matter by forming new vesicles derived from the plasma membrane (ENE-2.F.2). Phagocytosis is cellular eating. Pinocytosis is cellular drinking.**
	C	In exocytosis, internal vesicles fuse with the plasma membrane and secrete large macromolecules out of the cell. (ENE-2.F.2)
	D	In exocytosis, internal vesicles fuse with the plasma membrane and secrete large macromolecules out of the cell. (ENE-2.F.2). Phagocytosis and pinocytosis are both types of endocytosis.
18	A	0.5M cell is less concentrated than 1.0M exterior solution. Water will move from the hypotonic solution (0.5M) to the hypertonic solution (1.0M). The water will leave the cell (and lose water to the exterior solution).
	B	0.5M cell is the same concentration as the 0.5M exterior solution. Water will move at equal rates into and out of the cell.
	C	**1.0M cell is more concentration than the 0.5M exterior solution. Water will move from the hypotonic solution (0.5M) to the hypertonic solution (1.0M). The water will leave the exterior solution and move into the cell.**
	D	0.5M cell is the same concentration as the 0.5M exterior solution. Water will move at equal rates into and out of the cell.

19	A	**Membranes and membrane-bound organelles in eukaryotic cells compartmentalize intracellular metabolic processes and specific enzymatic reactions. (ENE-2.K.1) Internal membranes facilitate cellular processes by minimizing competing interactions and by increasing surface areas where reactions can occur. (ENE-2.L.1)**
	B	Prokaryotic cells do not have a nucleus. Instead, they have a region of the cytoplasm called the nucleoid, where the DNA is found.
	C	The nucleus is still part of the volume of the cell.
	D	Eukaryotic cells have membrane bound organelles. This is one of the characteristics of eukaryotic cells.
20	A	**There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate. (ENE-1.M.1c)**
	B	The larger the organism, the lower the metabolic rate
	C	The question asks about the relationship with the size of the organism and this answer choice refers to the cells.
	D	The question asks about the relationship with the size of the organism and this answer choice refers to the cells.

Free Response Practice

2025 #1

This question is in Unit 6.

2024 #3

To investigate whether red blood cells of animals lose the ability to take in glucose from their environment as they age, scientists collected red blood cells from guinea pigs that ranged in age from one day old to seven months old. Scientists incubated an equal number of red blood cells in separate culture dishes that contained a 300 nM solution of radioactively labeled glucose. The amount of radioactively labeled glucose present inside the red blood cells of each group was measured over time.

(a) **Describe** a difference between passive transport and active transport.

(b) **Justify** why the scientists used an equal number of red blood cells in each culture dish as a control.

(c) Glucose transporters are required for the facilitated diffusion of glucose into red blood cells. The scientists claim that the expression of the gene encoding these transporters decreases as guinea pigs age. If the scientists' claim is supported by experimental data, **predict** the effect of increased age on the amount of radioactively labeled glucose present inside the cells of each group.

(d) **Justify** your prediction in part (c)

2023 #2

This question is in Unit 5.

2022 #1

This question is in Unit 4.

2021 #2

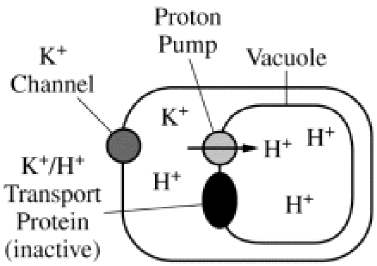
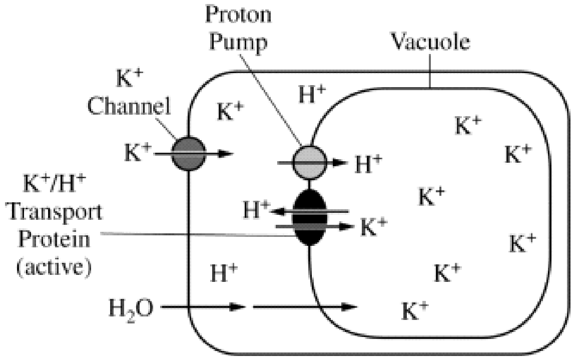
This question is found in Unit 6.

2019 #2

This question is found in Unit 8.

2019 #8

TABLE 1. CHANGES IN MORNING GLORY PETAL CELLS DURING FLOWER OPENING

	BUD	OPEN FLOWER
		
Vacuole pH	6.6	7.7
Flower Color	Red	Blue
Cell Volume	Small	Large

The petal color of the Mexican morning glory (*Ipomoea tricolor*) changes from red to blue, and the petal cells swell during flower opening. The pigment heavenly blue anthocyanin is found in the vacuole of petal cells. Petal color is determined by the pH of the vacuole. A model of a morning glory petal cell before and after flower opening is shown in Table 1.

(a) **Identify** the cellular component in the model that is responsible for the increase in the pH of the vacuole during flower opening AND **describe** the component's role in changing the pH of the vacuole.

(b) A researcher claims that the activation of the K$^+$/H$^+$ transport protein causes the vacuole to swell with water. **Provide reasoning** to support the researcher's claim.

2018 #2

This question is in Unit 4.

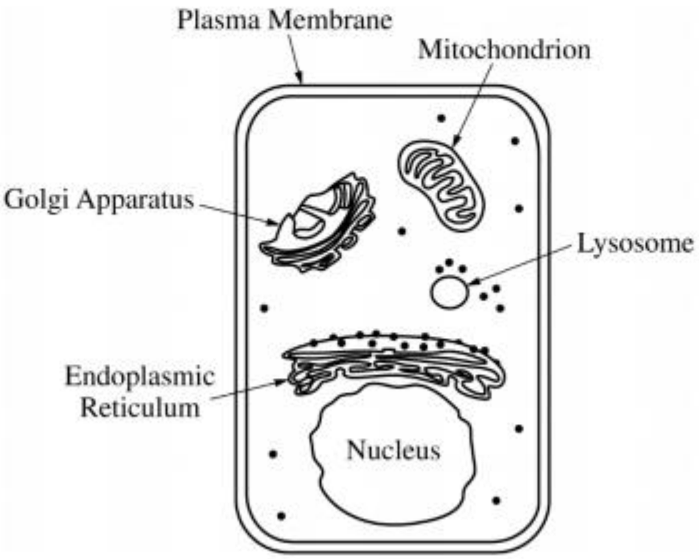
2018 #6

Cystic fibrosis is a genetic condition that is associated with defects in the CFTR protein. The CFTR protein is a gated ion channel that requires ATP binding in order to allow chloride ions (Cl$^-$) to diffuse across the membrane.

(a) In the provided model of a cell, **draw** arrows to describe the pathway for production of a normal CFTR protein from gene expression to final cellular location.

(b) **Identify** the most likely cellular location of the ribosomes that synthesize CFTR protein.

(c) **Identify** the most likely cellular location of a mutant CFTR protein that has an amino acid substitution in the ATP-binding site.



2017 #8

Estrogens are small hydrophobic lipid hormones that promote cell division and the development of reproductive structures in mammals. Estrogens passively diffuse across the plasma membrane and bind to their receptor proteins in the cytoplasm of target cells.

(a) **Describe** ONE characteristic of the plasma membrane that allows estrogens to passively cross the membrane.

(b) In a laboratory experiment, a researcher generates antibodies that bind to purified estrogen receptors extracted from cells. The researcher uses the antibodies in an attempt to treat estrogen-dependent cancers but finds that the treatment is ineffective. **Explain** the ineffectiveness of the antibodies for treating estrogen-dependent cancers.

Note: Part (b) is out of scope due to the antibodies, but with the information that antibodies are PROTEINS, you could answer this question

2016 #1

This question is in Unit 7.

2013 #6

The following data were collected by observing subcellular structures of three different types of eukaryotic cells.

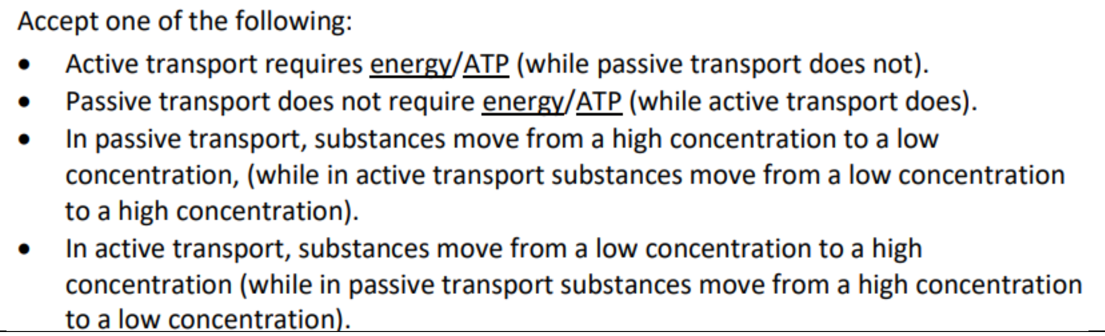
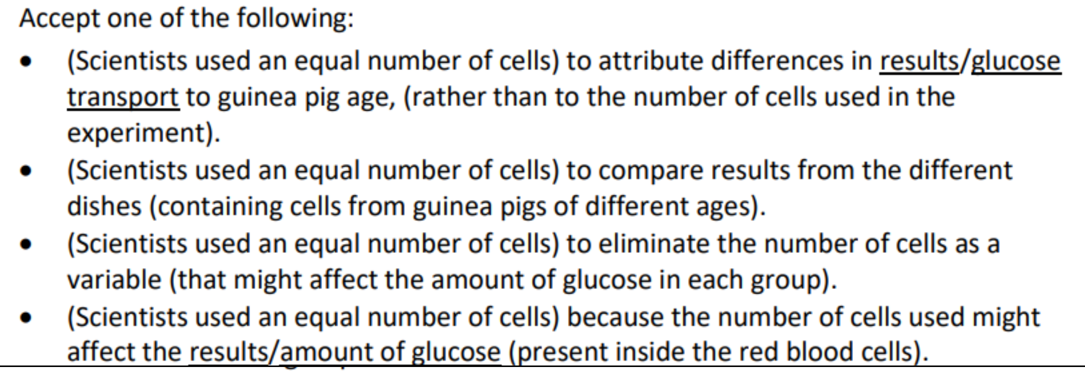
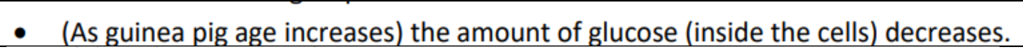
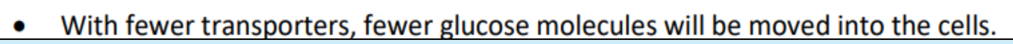
RELATIVE AMOUNTS OF ORGANELLES IN THREE CELL TYPES

Cell Type	Smooth ER	Rough ER	Mitochondria	Cilia	Golgi Bodies
X	Small amount	Small amount	Large number	Present	Small amount
Y	Large amount	Large amount	Moderate number	Absent	Large amount
Z	Absent	Absent	Absent	Absent	Absent

Based on an analysis of the data, **identify** a likely primary function of each cell type and **explain** how the data support the identification.

Free Response Scoring Guidelines

2024 #3	
Course Content	**Practice and Skill**
2.5: Membrane Transport • 2.5.A: Describe the mechanisms that organisms use to maintain solute and water balance. 2.6: Facilitated Diffusion • 2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane.	1.A: Describe biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	 Accept one of the following: • Active transport requires energy/ATP (while passive transport does not). • Passive transport does not require energy/ATP (while active transport does). • In passive transport, substances move from a high concentration to a low concentration, (while in active transport substances move from a low concentration to a high concentration). • In active transport, substances move from a low concentration to a high concentration (while in passive transport substances move from a high concentration to a low concentration).
(b)	 Accept one of the following: • (Scientists used an equal number of cells) to attribute differences in results/glucose transport to guinea pig age, (rather than to the number of cells used in the experiment). • (Scientists used an equal number of cells) to compare results from the different dishes (containing cells from guinea pigs of different ages). • (Scientists used an equal number of cells) to eliminate the number of cells as a variable (that might affect the amount of glucose in each group). • (Scientists used an equal number of cells) because the number of cells used might affect the results/amount of glucose (present inside the red blood cells).
(c)	 • (As guinea pig age increases) the amount of glucose (inside the cells) decreases.
(d)	 • With fewer transporters, fewer glucose molecules will be moved into the cells.

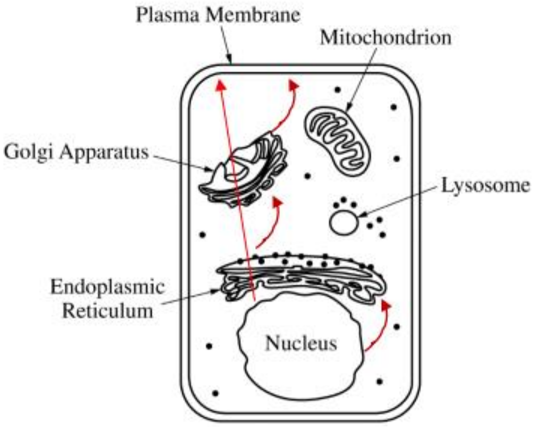
Scoring Guidelines	
Mean: 2.39	Standard Deviation: 1.27

2019 #8	
Course Content	**Practice and Skill**
2.6: Facilitated Diffusion • 2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane. 2.7: Tonicity and Osmoregulation • 2.7.A: Explain how concentration gradients affect the movement of molecules across membranes.	2.A: Describe characteristics of visual representations of biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines
(a)	**Identification (1 point)** - (K^+/H^+) transport protein **Description (1 point)** - It moves H^+ out of the vacuole.
(b)	**Reasoning (1 point)** - The concentration of solute (K^+) is increasing inside the vacuole. - The solute (K^+) is moving into the vacuole, making it hypertonic/hyperosmotic/lowering water potential.

Scoring Guidelines	
Mean: 1.04	Standard Deviation: 1.05

2018 #6	
Course Content	Practice and Skill
2.1: Cell Structure and Function - 2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells. 2.6: Facilitated Diffusion - 2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane.	1.A: Describe biological concepts and processes. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Part	Scoring Guidelines
(a)	**Drawing (1 point)**  Plasma Membrane Mitochondrion Golgi Apparatus Lysosome Endoplasmic Reticulum Nucleus The response must follow this pathway: nucleus/nuclear envelope → endoplasmic reticulum → Golgi apparatus → plasma membrane. The response may be in the form of a continuous arrow or multiple discontinuous arrows.
(b)	**Identification (1 point)** - (Rough) Endoplasmic Reticulum/ER
(c)	**Identification (1 point)** - In the (cellular/plasma) membrane

Scoring Guidelines	
Mean: 0.89	Standard Deviation: 0.88

2017 #8

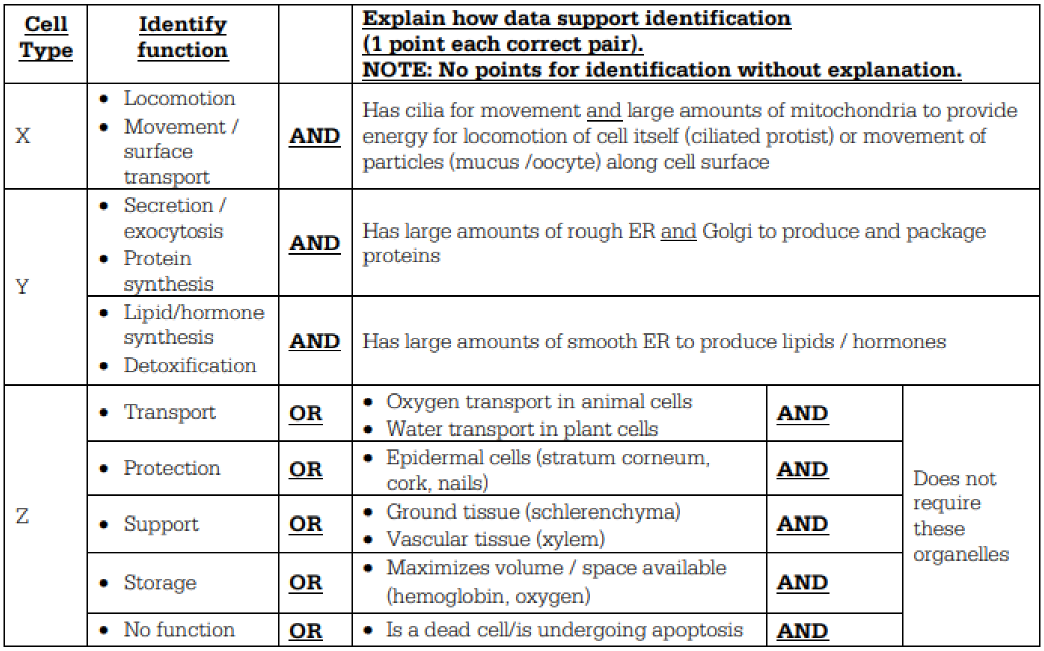
Part	Scoring Guidelines
(a)	**Description (1 point)** • Hydrophobic/nonpolar • Space between phospholipids
(b)	**Explanation (2 points)** • Antibodies are unable to enter the cell. • (Extracellular) antibodies will not bind to (intracellular) estrogen receptors.

Scoring Guidelines	
Mean: 0.60	Standard Deviation: 0.79

2013 #6

Course Content	Practice and Skill
2.1: Cell Structure and Function • 2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells.	6.A: Make a scientific claim. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines



Cell Type	**Identify function**		**Explain how data support identification (1 point each correct pair). NOTE: No points for identification without explanation.**		
X	• Locomotion • Movement / surface transport	**AND**	Has cilia for movement and large amounts of mitochondria to provide energy for locomotion of cell itself (ciliated protist) or movement of particles (mucus /oocyte) along cell surface		
Y	• Secretion / exocytosis • Protein synthesis	**AND**	Has large amounts of rough ER and Golgi to produce and package proteins		
	• Lipid/hormone synthesis • Detoxification	**AND**	Has large amounts of smooth ER to produce lipids / hormones		
Z	• Transport	**OR**	• Oxygen transport in animal cells • Water transport in plant cells	**AND**	Does not require these organelles
	• Protection	**OR**	• Epidermal cells (stratum corneum, cork, nails)	**AND**	
	• Support	**OR**	• Ground tissue (schlerenchyma) • Vascular tissue (xylem)	**AND**	
	• Storage	**OR**	• Maximizes volume / space available (hemoglobin, oxygen)	**AND**	
	• No function	**OR**	• Is a dead cell/is undergoing apoptosis	**AND**	

Scoring Guidelines	
Mean: 0.69	Standard Deviation: 0.79

Unit 3: Cellular Energetics

Topic	Learning Objective(s)
3.1 Enzymes	**3.1.A:** Explain how enzymes affect the rate of biological reactions.
3.2 Environmental Impact on Enzyme Function	**3.2.A:** Explain how changes to the structure of an enzyme may affect its function. **3.2.B:** Explain how the cellular environment affects enzyme activity.
3.3 Cellular Energy	**3.3.A:** Describe the role of energy in living organisms. **3.3.B:** Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.
3.4 Photosynthesis	**3.4.A:** Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy **3.4.B:** Explain how cells capture energy from light and transfer it to biological molecules for storage and use.
3.5 Cellular Respiration	**3.5.A:** Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules. **3.5.B:** Explain how cells obtain energy from biological macromolecules in order to power cellular functions.

Additional Resources

Unit 3 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

Topic 3.1: Enzymes

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">3.1.A: Explain how enzymes affect the rate of biological reactions.</td></tr>
<tr><td>3.1.A.1: The structure and function of enzymes contribute to the regulation of biological processes. Enzymes are proteins that are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy.</td><td>☐ I can describe how the structure and function of enzymes contribute to the regulation of biological processes.
☐ I can describe an enzyme.
☐ I can describe how an enzyme affects reaction rate.
☐ I can explain the difference between an enzyme-catalyzed and uncatalyzed reaction.</td></tr>
</table>

1. What is an enzyme?
2. What is the structure of an enzyme?
    a. How does the structure of an enzyme contribute to the regulation of biological processes?
3. What is the function of an enzyme?
    a. How does the function of an enzyme contribute to the regulation of biological processes?
    b. How does the enzyme complete this function?
4. What is the monomer that makes up an enzyme?
5. How does an enzyme affect the rate of a reaction?
6. What is an enzyme-catalyzed reaction?
7. How is the activation energy of an enzyme-catalyzed reaction and an uncatalyzed reaction different?
8. How is the change in free energy of an enzyme-catalyzed reaction and an uncatalyzed reaction different?
9. How is the reaction rate of an enzyme-catalyzed reaction and an uncatalyzed reaction different?
10. True or False? Enzymes affect the Gibbs Free Energy of a chemical reaction.

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">3.1.A: Explain how enzymes affect the rate of biological reactions.</td></tr>
<tr><td>3.1.A.2: For an enzyme-mediated chemical reaction to occur, the shape and charge of the substrate must be compatible with the active site of the enzyme. This is illustrated by the enzyme-substrate complex model.</td><td>☐ I can describe the enzyme-substrate complex model.
☐ I can describe how the shape and charge of a substrate affects the binding to the active site of the enzyme.</td></tr>
</table>

11. How does a substrate bind to an enzyme?
    a. What is this called when the enzyme and substrate are bonded together?
12. What happens after the substrate binds to the enzyme?
13. How does the shape and charge of a substrate affect the binding to the active site of the enzyme

Topic 3.2: Environmental Impact on Enzyme Function

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">3.2.A: Explain how changes to the structure of an enzyme may affect its function.</td></tr>
<tr><td>3.2.A.1: Change to the molecular structure of a component in an enzymatic system may result in a change to its function or efficiency.
I. Denaturation of proteins, such as enzymes, occurs when the protein structure is disrupted by a change in temperature, pH, or chemical environment, eliminating the ability to catalyze reactions.
II. Environmental temperatures and pH outside the optimal range for a given enzyme will cause changes to its structure (by disrupting the hydrogen bonds), altering the efficiency with which it catalyzes reactions.</td><td>☐ I can identify environmental conditions that change the structure of an enzyme.
☐ I can explain ways environmental conditions modify the structure of an enzyme.
☐ I can describe changes that will occur to enzymes due to environmental conditions.
☐ I can predict changes to reaction rates due to changes in structure of enzymes.</td></tr>
</table>

1. Identify two conditions that affect the structure of an enzyme.
    a. What happens to the structure of the enzyme in these conditions?
2. How does a change in structure affect the function of an enzyme?
3. Predict the three different possible outcomes when there is a change in structure of an enzyme.
4. What happens to the pH when the concentration of hydrogen ions…
    a. Increases?
    b. Decreases?
5. What happens to an enzyme when the pH…
    a. Increases?
    b. Decreases?
6. How does the temperature affect the kinetic energy of the molecules?
7. What happens to an enzyme when the temperature …
    a. Increases?
    b. Decreases?

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">3.2.A: Explain how changes to the structure of an enzyme may affect its function.</td></tr>
<tr><td>3.2.A.2: In some cases, enzyme denaturation is reversible, allowing the enzyme to regain activity</td><td>☐ I can describe ways the process of denaturation can be reversible.</td></tr>
</table>

8. What is denaturation?
9. True or False? Denaturation can be reversible.
10. Identify one example of a protein that is reversible after denaturation.
11. Identify one example of a protein that is nonreversible after denaturation.

12. Describe how the process of denaturation can be reversible.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.2.B: Explain how the cellular environment affects enzyme activity.	
3.2.B.1: The relative concentrations of substrates and products determine how efficiently an enzymatic reaction proceeds.	☐ I can explain ways the concentration of substrates and products affects enzyme activity.

13. How does the concentration of substrates affect the reaction rate?
14. How does the concentration of products affect the reaction rate?
    a. What is it called when the product builds up and slows the reaction rate?
15. Justify the claim that the reaction rate will increase with an increase of substrate concentration.
16. Explain why even with the addition of more substrate the reaction rate will level off after a certain amount of time.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.2.B: Explain how the cellular environment affects enzyme activity.	
3.2.B.2: Higher environmental temperatures increase the average speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction until the optimal temperature is achieved.	☐ I can describe the effect on molecules as environmental temperature changes. ☐ I can explain ways temperature changes affect enzyme activity. ☐ I can describe the effect on reaction rate with a change in the environmental temperature.

17. Describe the effect of high environmental temperatures on the average speed of molecular movement in a solution.
18. How is the frequency of collisions affected by…
    a. Increased temperature?
    b. Decreased temperature?
19. How does temperature affect the rate of a reaction?
20. Describe what happens to an enzyme if the optimal temperature is surpassed.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.2.B: Explain how the cellular environment affects enzyme activity.	
3.2.B.3: Competitive inhibitor molecules can bind reversibly to the active site of the enzyme. Noncompetitive inhibitors can bind to allosteric sites, changing the activity of the enzyme.	☐ I can explain ways competitive inhibitors affect enzyme activity. ☐ I can explain ways to overcome competitive inhibitor's effect on enzyme activity. ☐ I can explain ways noncompetitive inhibitors affect enzyme activity.

14. What is a competitive inhibitor?
15. How can a researcher overcome a competitive inhibitor?
16. Describe the binding site for a competitive inhibitor.
17. What is a noncompetitive inhibitor?
18. Describe the binding site for a noncompetitive inhibitor.
19. How does an inhibitor affect reaction rate?

Topic 3.3: Cellular Energy

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.3.A: Describe the role of energy in living organisms.	
3.3.A.1: All living systems require an input of energy.	☐ I can describe the role of energy in living organisms. ☐ I can describe that living systems require a constant input of energy.

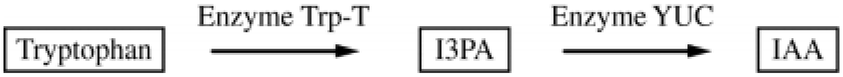
1. How are cellular processes powered?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.3.A: Describe the role of energy in living organisms.	
3.3.A.2: Life requires a highly ordered system and does not violate the first and second laws of thermodynamics. I. Energy input must exceed energy loss to maintain order and to power cellular processes. II. Cellular processes that release energy may be coupled with cellular processes that require energy. III. Significant loss of order or energy flow results in death. ☒ Exclusion Statement: Students will need to understand the concept of energy, but the equation for Gibbs free energy is beyond the scope of the AP Exam.	☐ I can describe the laws of thermodynamics. ☐ I can describe ways that order is maintained. ☐ I can describe ways that cellular processes are powered. ☐ I can describe energy coupling. ☐ I can describe the result of loss of energy or energy flow.

2. What is the first law of thermodynamics?
3. What is the second law of thermodynamics?
4. How is order (entropy) maintained in a system?
5. How are cellular processes powered?
6. What is an exergonic reaction?
7. What is an endergonic reaction?
8. Describe the process of energy coupling.
9. Explain why energy coupling is needed within the cell.
10. What happens if there is a decrease in available energy or a loss of order?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.3.A: Describe the role of energy in living organisms.	
3.3.A.3: Energy-related pathways in biological systems are sequential to allow for a more controlled transfer of energy. A product of a reaction in a metabolic pathway is typically the reactant for the subsequent step in the pathway	☐ I can describe metabolic pathways. ☐ I can describe the function of controlled energy pathways. ☐ I can describe the relationship between products of a reaction and reactants of a subsequent reaction.

11. What is a metabolic pathway?
12. How do catabolic and anabolic pathways differ?
13. In a metabolic pathway, how does the product of one step compare to the reactant of the next step?
14. Using the given pathway from 2019 #1 free response, how is the pathway affected by:



    a. Decrease in Tryptophan
    b. Decrease in Enzyme Trp-T
    c. Decrease in I3PA
    d. Decrease in Enzyme YUC
    e. Decrease in IAA

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.3.B: Explain how shared, conserved, and fundamental processes and features support the concept of common ancestry for all organisms.	
3.3.B.1: Core metabolic pathways (e.g., glycolysis, oxidative phosphorylation) are conserved across all currently recognized domains (Archaea, Bacteria, and Eukarya)	☐ I can explain how core metabolic pathways are conserved across all domains. ☐ I can determine the meaning that core metabolic pathways are conserved across all domains.

15. TRUE or FALSE? All organisms perform glycolysis.
16. Explain how glycolysis has been conserved across all domains.
17. Justify the claim that glycolysis first occurred in the common ancestor for all living organisms.
18. Explain how oxidative phosphorylation is performed in archaea.
19. Explain how oxidative phosphorylation is performed in bacteria.
20. Explain how oxidative phosphorylation is performed in eukaryotes.

Topic 3.4: Photosynthesis

<table>
<tr><th colspan="2">**Energetics:**
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">**3.4.A:** Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy
☒ **Exclusion Statement:**
Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam</td></tr>
<tr><td>**3.4.A.1:** Photosynthesis is the series of reactions that use carbon dioxide (CO_2), water (H_2O), and light energy to make carbohydrates and oxygen (O_2).
I. Photosynthetic organisms capture energy from the sun and produce sugars that can be used in biological processes or stored.
II. Photosynthesis first evolved in prokaryotic organisms.
III. Scientific evidence supports the claim that prokaryotic (cyanobacterial) photosynthesis was responsible for the production of an oxygenated atmosphere.
IV. Prokaryotic photosynthetic pathways were the foundation of eukaryotic photosynthesis</td><td>☐ I can identify the products and reactants of photosynthesis.
☐ I can describe photosynthesis.
☐ I can identify organisms able to undergo photosynthesis.
☐ I can describe the photosynthetic processes that allow organisms to capture and store energy.
☐ I can describe the location of photosynthesis evolution.
☐ I can provide evidence to support oxygenation to atmosphere from cyanobacteria.
☐ I can describe the foundation of eukaryotic photosynthesis.</td></tr>
</table>

1. What is photosynthesis?
2. Identify the reactants and products for photosynthesis.
3. Describe the process of photosynthesis.
4. What types of organisms are able to perform photosynthesis?
5. Identify TWO examples of photosynthetic organisms.
6. What organism first evolved photosynthesis?
7. Identify one piece of evidence that supports oxygenation to atmosphere from cyanobacteria.
8. Describe how the prokaryotic photosynthetic pathway has led to eukaryotic photosynthesis.

Energetics:

Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.

3.4.A: Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy

☒ **Exclusion Statement:**

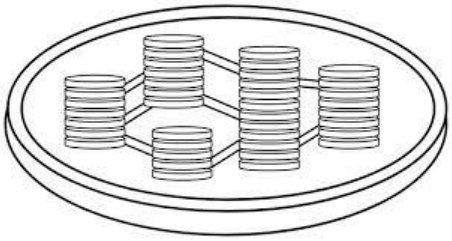
Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam

3.4.A.2: Stroma and thylakoids are found within the chloroplast.

I. The stroma is the fluid within the inner chloroplast membrane and outside the thylakoid. The carbon fixation (Calvin cycle) reactions of photosynthesis occur in the stroma.
II. The thylakoid membranes contain chlorophyll pigments organized into two photosystems, as well as electron transport proteins.
III. Thylakoids are organized in stacks called grana. The light reactions of photosynthesis occur in the grana.

☐ I can identify and locate the stroma and thylakoid
☐ I can describe the stroma, thylakoid membrane, and grana
☐ I can describe the processes that take place in the stroma, thylakoid membrane, and grana.
☐

9. What is the structure and function of a chloroplast?
    a. How does the structure of the chloroplast aid in the function?
10. Label the chloroplast with the following terms:
    a. Stroma
    b. Thylakoid
    c. Grana
    d. Thylakoid Membrane
    e. Thylakoid Space



11. What is the stroma?
12. Describe the process that takes place in the stroma.
13. What is the thylakoid membrane?
14. Describe the process that takes place in the thylakoid membrane.
15. What is chlorophyll?
16. Where would you find chlorophyll in the chloroplast?
17. How is the thylakoid organized to facilitate ATP and NADPH synthesis?

<table>
<tr><th colspan="2">Energetics:
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<tr><td colspan="2">3.4.A: Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy
⌧ Exclusion Statement:
Memorization of the steps in the Calvin cycle, the structure of the molecules, and the names of the enzymes involved, with the exception of ATP synthase, is beyond the scope of the AP Exam</td></tr>
<tr><td>3.4.A.3: The light reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules in the Calvin cycle. This provides energy for metabolic processes.</td><td>☐ I can describe the light reactions.
☐ I can describe the dark reactions (Calvin cycle)
☐ I can explain the process of energy coupling involved in photosynthesis.
☐ I can describe the energy coupling process involved in photosynthesis.</td></tr>
</table>

18. Describe the light reactions.
19. Describe the dark reactions (aka the Calvin Cycle).
20. How is energy coupled between the light reactions and the Calvin cycle?

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.</td></tr>
<tr><td>3.4.B.1: Electron transport chain (ETC) reactions occur in chloroplasts, in mitochondria, and across prokaryotic plasma membranes. In photosynthesis, electrons that pass through the thylakoid membrane are picked up and ultimately transferred to NADP+, reducing it to NADPH in photosystem I.
⌧ Exclusion Statement:
The full names of the specific electron carriers in the electron transport chain are beyond the scope of the AP Exam.
⌧ Exclusion Statement:
Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.</td><td>☐ I can identify locations of the electron transport chain (ETC).
☐ I can describe the process of the electron transport chain in chloroplasts, mitochondria, and across prokaryotic plasma membranes.
☐ I can describe the synthesis of NADPH in photosynthesis.</td></tr>
</table>

21. What is the electron transport chain?
22. Where do the electron transport chain reactions take place?
23. Describe the process of the electron transport chain in photosynthesis.
24. How does the electron transport chain in cellular respiration compare to the electron transport chain in photosynthesis?

25. How does the electron transport chain in prokaryotic plasma membranes compare to the electron transport chain in photosynthesis?
26. How is NADPH formed during the light reactions?

<table>
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<tr><td>3.4.B.2: During photosynthesis, chlorophylls absorb energy from light, boosting electrons to a higher energy level in photosystems I and II. Water then splits, supplying electrons to replace those lost from photosystem II.</td><td>☐ I can describe the light reaction in photosynthesis.
☐ I can identify the location of photolysis and describe the process of photolysis.</td></tr>
</table>

27. What are the light reactions?
28. Where do the light reactions take place?
29. Describe the process of the light reactions in photosynthesis.
30. Describe the pathway of an electron through the light reactions with…
    a. Linear electron flow?
    b. Cyclic electron flow?
31. What is photolysis?
    a. Identify the location where photolysis takes place.
    b. Describe the process of photolysis.
32. Justify the claim that photosynthesis would halt if photolysis was inhibited.

<table>
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<tr><td colspan="2">3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.</td></tr>
<tr><td>3.4.B.3: Photosystems I and II are embedded in the thylakoid membranes of chloroplasts and are connected by the transfer of electrons through an ETC.</td><td>☐ I can describe the structure and location of photosystems I and II.</td></tr>
</table>

33. Describe the structure of the thylakoid membrane in chloroplasts.
34. Diagram the thylakoid membrane including and labeling photosystem I and II, the electron transport system, and the final electron acceptor.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	
3.4.B.4: When electrons are transferred between molecules in a series of oxidation/reduction reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the thylakoid membrane. The membrane separates a region of low proton concentration outside the thylakoid membrane from a region of high proton concentration inside the thylakoid membrane.	☐ *I can describe the electron transport chain in photosynthesis.* ☐ *I can explain how the proton gradient is generated in photosynthesis.*

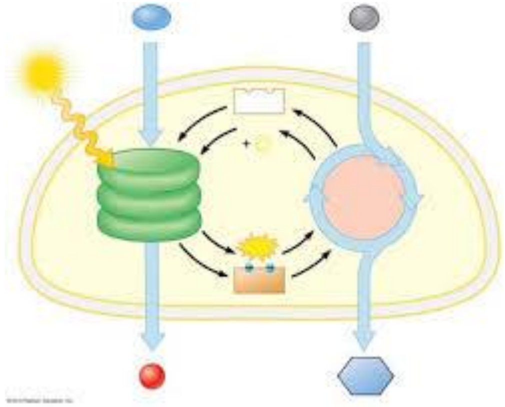
35. Describe the electron transport chain in photosynthesis.
36. Explain how the proton gradient is generated in photosynthesis.
37. Identify which side of the membrane would have a lower pH.
    a. Explain why this side of the membrane would have a lower pH (Hint: think hydrogen ions and direction of proton movement)

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	
3.4.B.5: The formation of the proton gradient is linked to the synthesis of ATP from ADP and inorganic phosphate via ATP synthase. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate; this is known as photophosphorylation	☐ *I can explain how the proton gradient is connected to ATP synthesis.* ☐ *I can describe chemiosmosis.* ☐ *I can describe photophosphorylation.* ☐ *I can describe the synthesis of ATP in photosynthesis.*

38. Describe how the proton gradient in a chloroplast facilitates ATP synthesis.
39. Describe chemiosmosis.
40. Describe photophosphorylation.
41. This is energy coupling, identify the exergonic reaction and the endergonic reaction.
42. What is the product of photophosphorylation?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	
3.4.B.6: The energy captured in the light reactions and transferred to ATP and NADPH powers the production of carbohydrates from carbon dioxide in the Calvin cycle. This occurs in the stroma of the chloroplast.	☐ I can describe how the light reactions and the Calvin cycle are connected.

43. Describe how the light reactions and the Calvin cycle are connected.
44. Describe the light reactions.
45. Describe the Calvin cycle.
46. Label the diagram with ADP, ATP, Calvin cycle, CO_2, H_2O, light, light reactions, $NADP^+$, NADPH, O_2, sugar



Topic 3.5: Cellular Respiration

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.</td></tr>
<tr><td>3.5.A.1: Cellular respiration uses energy from biological macromolecules to synthesize ATP. Respiration and fermentation are characteristic of all forms of life.</td><td>☐ I can describe the processes that allow organisms to use energy stored in biological macromolecules.
☐ I can describe cellular respiration.
☐ I can describe fermentation.</td></tr>
</table>

1. What is cellular respiration?
2. What is fermentation?

<table>
<tr><th colspan="2">Energetics:
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<tr><td colspan="2">3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.</td></tr>
<tr><td>3.5.A.2: Aerobic cellular respiration in eukaryotes involves a series of coordinated enzyme-catalyzed reactions that capture energy from biological macromolecules.</td><td>☐ I can describe cellular respiration.</td></tr>
</table>

3. What are the three steps involved in cellular respiration?
4. What is the function of each step in cellular respiration?
5. TRUE or FALSE: Each step in cellular respiration results in energy being captured and stored as ATP.
6. Which macromolecules can be used by the cell to capture energy?

<table>
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<tr><td colspan="2">3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.</td></tr>
<tr><td>3.5.A.3: The ETC transfers electrons in a series of oxidation-reduction reactions that establish an electrochemical gradient across membranes.
i. In cellular respiration, electrons delivered by NADH and $FADH_2$ are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. Aerobic prokaryotes use oxygen as a terminal electron acceptor, while anaerobic prokaryotes use other molecules.
ii. The transfer of electrons, through the ETC, is accompanied by the formation of a proton gradient across the inner</td><td>☐ I can describe the electron transport chain.
☐ I can describe ways that electrons are moved through the process of cellular respiration.
☐ I can identify the terminal electron acceptor in each electron transport chain.
☐ I can describe the process of electrons moving down the electron transport chain.
☐ I can describe the process that generates the proton gradient.
☐ I can identify the location with the high proton concentration.
☐ I can compare electron transport chain in eukaryotes and prokaryotes.</td></tr>
</table>

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mitochondrial membrane, with the membrane(s) separating a region of high proton concentration outside the membrane from a region of low proton concentration inside the membrane. The folding of the inner membrane increases the surface area, which allows for more ATP to be synthesized. In prokaryotes, the passage of electrons is accompanied by the movement of protons across the plasma membrane. iii. The flow of protons back through membrane-bound ATP synthase by chemiosmosis drives the formation of ATP from ADP and inorganic phosphate. This is known as oxidative phosphorylation in aerobic cellular respiration. iv. In aerobic cellular respiration, decoupling oxidative phosphorylation from electron transport generates heat. This heat can be used by endothermic organisms to regulate body temperature. ☒ **Exclusion Statement:** *The full names of the specific electron carriers in the electron transport chain are beyond the scope of the AP Exam.* ☒ **Exclusion Statement:** *Specific steps, names of enzymes, and intermediates of the pathways for these processes are beyond the scope of this course and the AP Exam.*	☐ I can describe chemiosmosis. ☐ I can describe oxidative phosphorylation. ☐ I can describe ways that endotherms maintain their body temperature.

7. What is the electron transport chain?
   *Note: BEWARE of shorthand of ETC in a FRQ as it could be read as "excreta"
8. Where is the electron transport chain in a mitochondrion?
9. Where is the electron transport chain in a prokaryote?
10. Describe how the electrons are brought to the electron transport chain.
11. What occurs as electrons are transferred from one cytochrome to the next in the electron transport chain?
12. What is the final electron acceptor in the electron transport chain during aerobic respiration?
13. Identify another molecule that can be used as a final electron acceptor in anaerobic respiration?
14. Describe the proton movement as the electron moves through the electron transport chain.
15. Which side of the membrane will have a higher concentration of hydrogen ions?

    a. How does this affect the pH of that region?
16. Explain why the cristae is highly folded.
17. Describe chemiosmosis.
18. What is the function of ATP Synthase?
19. Describe oxidative phosphorylation.
20. What is decoupling oxidative phosphorylation?
    a. How does it generate heat?
    b. How is this different than the oxidative phosphorylation?

<table>
<tr><th colspan="2">Energetics:
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<tr><td colspan="2">3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
☒ Exclusion Statement:
Memorization of the steps in glycolysis and the Krebs cycle, and of the structures of the molecules and the names of the enzymes involved, is beyond the scope of this course and the AP Exam.</td></tr>
<tr><td>3.5.B.1: Glycolysis is a biochemical pathway that releases the energy in glucose molecules to form ATP (from ADP and inorganic phosphate), NADH (from NAD^+), and pyruvate.</td><td>☐ I can describe glycolysis.
☐ I can identify the reactants and products of glycolysis.</td></tr>
</table>

21. What is glycolysis?
22. Where does glycolysis take place?
23. Identify the reactants and products of glycolysis.
24. TRUE or FALSE: Glycolysis requires oxygen.
25. How is ATP synthesized in glycolysis?

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<tr><td>3.5.B.2: Pyruvate is transported from the cytosol to the mitochondrion where oxidation occurs. This process releases electrons during the Krebs (citric acid) cycle, reducing NAD^+ to NADH and FAD to $FADH_2$, and releasing CO_2.</td><td>☐ I can describe pyruvate oxidation.
☐ I can identify the reactants and products of pyruvate oxidation.</td></tr>
</table>

26. What is pyruvate oxidation?
27. Where does pyruvate oxidation take place?
28. Identify the reactants and products of pyruvate oxidation.
29. TRUE or FALSE: Pyruvate oxidation requires oxygen.

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<tr><td>3.5.B.3: The Krebs cycle takes place in the mitochondrial matrix. During the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred by the coenzymes, NAD+ and FAD.</td><td>☐ I can identify the location of the Krebs cycle.
☐ I can describe the Krebs cycle.
☐ I can identify the reactants and products of the Krebs cycle.</td></tr>
</table>

30. What is the Krebs Cycle?
31. Where does the Krebs Cycle take place?
32. Identify the reactants and products of the Krebs cycle.
33. TRUE or FALSE: The Krebs Cycle requires oxygen.
34. How is ATP synthesized in the Krebs Cycle?

<table>
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<tr><td colspan="2">3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
☒ Exclusion Statement:
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<tr><td>3.5.B.4: Electrons extracted in glycolysis and Krebs cycle reactions are transferred by NADH and FADH2 to the ETC in the inner mitochondrial membrane.</td><td>☐ I can explain how the electrons are transferred to the electron transport chain.</td></tr>
</table>

35. What is oxidation?
36. What is reduction?
37. What molecules are reduced in glycolysis and the Krebs cycle?
38. Where do these reduced molecules go to be oxidized?

<table>
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<tr><td>3.5.B.5: When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established.</td><td>☐ I can describe the process of the electron transport chain in cellular respiration.
☐ I can identify the proton gradient due to the electron transport chain.</td></tr>
</table>

39. What occurs as electrons are transferred from one cytochrome to the next in the electron transport chain?
40. What is the function of the electrochemical gradient formed during the electron transport chain?

<table>
<tr><th colspan="2">Energetics:
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<tr><td colspan="2">3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions.
☒ Exclusion Statement:
☒ Memorization of the steps in glycolysis and the Krebs cycle, and of the structures of the molecules and the names of the enzymes involved, is beyond the scope of this course and the AP Exam.</td></tr>
<tr><td>3.5.B.6: Fermentation allows glycolysis to proceed in the absence of oxygen and produces organic molecules such as alcohol and lactic acid.</td><td>☐ I can describe fermentation.
☐ I can identify the reactants and products of fermentation.</td></tr>
</table>

41. Describe the process of fermentation.
42. Where does the fermentation take place?
43. Identify the reactants and products of the fermentation.
44. TRUE or FALSE: ATP is synthesized during fermentation.
45. What process precedes fermentation to aid in ATP synthesis?
46. Why is it more favorable for a cell to undergo aerobic respiration instead of fermentation.

Multiple Choice Practice

1. The enzyme trypsin aids in protein digestion in the small intestine. The relative activity of trypsin at different pH values is shown in Figure 1.

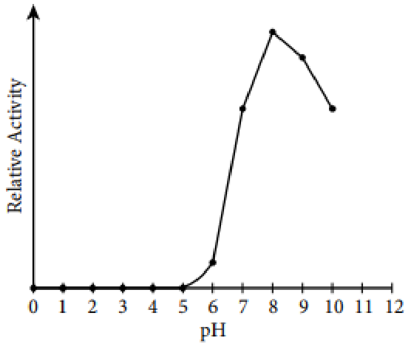


Figure 1. Effect of pH on the activity of trypsin

Which of the following statements best explains the activity levels of trypsin shown in Figure 1?
   a. The small intestine releases inhibitor molecules that block the activity of trypsin unless it is at its optimum pH.
   b. The number of effective collisions between trypsin and its substrate increase at higher pH values.
   c. As pH values increase, the substrate concentration decreases, leading to an eventual decline in the rate of the trypsin-catalyzed reaction.
   d. At extremely low pH values, trypsin is denatured and cannot function efficiently

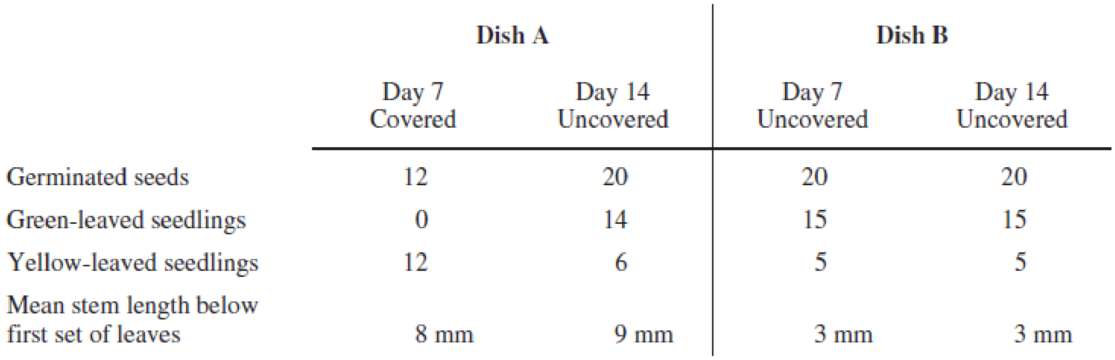
2. It is estimated that oxygen production first evolved in photosynthetic prokaryotes approximately 2.7 billion years ago. The first photosynthetic prokaryotes are presumed to be similar to today's cyanobacteria.

Which of the following best supports the claim that photosynthetic prokaryotes were responsible for the oxygen in Earth's atmosphere?
   a. The light reactions of photosynthesis split carbon dioxide into carbon and oxygen.
   b. The light reactions of photosynthesis split water into hydrogen ions and oxygen.
   c. The Calvin cycle splits glucose into carbon, hydrogen, and oxygen.
   d. The Calvin cycle splits water into hydrogen ions and oxygen.

3. Which of the following questions is most relevant to understanding the Calvin cycle?
   a. How does chlorophyll capture light?
   b. How is ATP used in the formation of 3-carbon carbohydrates?
   c. How is $NADP^+$ reduced to NADPH?
   d. How is ATP produced in chemiosmosis?

Use the following information to answer questions 4 & 5:

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.



	Dish A		Dish B	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

4. According to the results of this experiment, germination of tobacco seeds during the first week is
   a. increased by exposure to light
   b. unaffected by light intensity
   c. prevented by paper towels
   d. accelerated in green-leaved seedlings

5. Additional observations were made on day 21, and no yellow-leaved seedlings were found alive in either dish. This is most likely because
   a. yellow-leaved seedlings were unable to absorb water from the paper towels
   b. taller green-leaved seedlings blocked the light and prevented photosynthesis
   c. yellow-leaved seedlings were unable to convert light energy to chemical energy
   d. a higher rate of respiration in yellow-leaved seedlings depleted their stored nutrients

Use the following information to answer questions 6 – 10:

Photosynthetic activity can be measured using chloroplasts suspended in a buffered solution containing DCPIP, a dye that can accept electrons from the electron transport chain of photosynthesis. Transfer of electrons to DCPIP decreases the relative absorbance of a specific wavelength of light (605 nm) by a solution that contains the dye.

A buffered solution containing chloroplasts and DCPIP was divided equally among six identical samples. The samples were placed at various distances from a lamp, and then all samples were exposed to white light from the lamp for 60 minutes at room temperature. Sample 3 was wrapped in foil to prevent any light from reaching the solution. At 20-minute intervals, the photosynthetic activity in each sample was determined by measuring the relative absorbance of 605 nm light. The results of the experiment are provided below.

Relative Absorbance of 605 nm Light (arbitrary units)

Sample	Distance from Lamp (cm)	0 min	20 min	40 min	60 min
1	15	0.89	0.61	0.34	0.04
2	30	0.90	0.67	0.41	0.14
3*	30	0.88	0.87	0.86	0.87
4	45	0.86	0.69	0.47	0.26
5	60	0.92	0.75	0.59	0.41
6	75	0.88	0.79	0.71	0.58
* Wrapped in foil					

6. Which of the following provides the best indication that light is required for the activation of electron transfer reactions in chloroplasts?
    a. Calculating the rate of change of the absorbance for sample 1
    b. Comparing the observed results for sample 2 and sample 3
    c. Repeating the entire experimental procedure at night
    d. Including multiple trials for all the samples

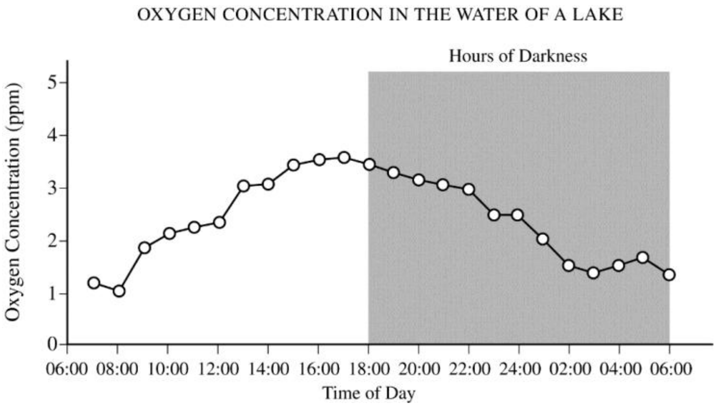
7. Which of the following can be reasonably concluded from the experimental results?
    a. Chloroplasts must be suspended in a buffer solution to function properly.
    b. The optimal temperature for activation of electron transfer is 25°C.
    c. DCPIP inhibits biochemical reactions in suspended chloroplasts.
    d. Light from a lamp can substitute for sunlight in stimulating chloroplast processes

8. If an additional sample containing the chloroplast/DCPIP solution was placed at a distance of 90 cm from the lamp, which of the following predictions would be most consistent with the experimental results?
    a. The concentration of DCPIP in the solution will increase exponentially.
    b. The absorbance at 60 minutes will be roughly equal to 1.4.
    c. The change in absorbance over time in the solution will be less than that of the other samples.
    d. The temperature of the solution will exceed 75°C.

9. Which of the following descriptions of photosynthesis best explains the results of the experiment?
    a. Availability of electrons for transfer to DCPIP depends on light energy.
    b. Movement of DCPIP across chloroplast membranes occurs in less than 60 minutes.
    c. Chlorophyll molecules degrade rapidly in the presence of DCPIP.
    d. DCPIP can only be used to measure photosynthetic activity at low light levels.

10. Which of the following scientific questions could be investigated using a similar experimental setup?
    a. How much carbon dioxide is required by a plant cell to produce one molecule of glucose?
    b. What wavelength of light best activates electron transfer reactions in chloroplasts?
    c. Which molecule in chloroplasts accepts activated electrons from DCPIP during photosynthesis?
    d. Are the same genes that are expressed in chloroplasts also expressed in mitochondria?

11. What most likely causes the trends in oxygen concentration shown in the graph below?
    a. The water becomes colder at night and thus holds more oxygen.
    b. Respiration in most organisms increases at night.
    c. More organisms are respiring at night than during the day.
    d. Photosynthesis produces more oxygen than is consumed by respiration during the day.



12. The chemical reaction for photosynthesis is

$$6\ CO_2 + 12\ H_2O + \text{light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

If the input water is labeled with a radioactive isotope of oxygen, ^{18}O, then the oxygen gas released as the reaction proceeds is also labeled with ^{18}O. Which of the following is the most likely explanation?

   a. During the light reactions of photosynthesis, water is split, the hydrogen atoms combine with the CO_2, and oxygen gas is released.
   b. During the light reactions of photosynthesis, water is split, removing electrons and protons, and oxygen gas is released.
   c. During the Calvin cycle, water is split, regenerating NADPH from NADP+, and oxygen gas is released.
   d. During the Calvin cycle, water is split, the hydrogen atoms are added to intermediates of sugar synthesis, and oxygen gas is released.

13. Students in a class measured the mass of various living organisms. They then kept the organisms in the dark for 24 hours before remeasuring them. None of the organisms were provided with nutrients during the 24-hour period. The data are as follows.

Organism	Starting Mass (g)	Final Mass (g)
Elodea (submerged aquatic plant)	15.10	14.01
Goldfish	10.10	9.84
Sea anemone	25.60	24.98

Which of the following is the best explanation for the pattern of change in mass of the organisms over time?

   a. Water loss due to evaporation
   b. Cellular respiration
   c. The law of conservation of matter
   d. Growth and reproduction

Use the following information to answer questions 14 & 15:

An experiment to measure the rate of respiration in crickets and mice at 10°C and 25°C was performed using a respirometer, an apparatus that measures changes in gas volume. Respiration was measured in mL of O_2 consumed per gram of organism over several five-minute trials and the following data were obtained.

Organism	Temperature (°C)	Average respiration ($mL\ O_2/g/min$)
Mouse	10	0.0518
Mouse	25	0.0321
Cricket	10	0.0013
Cricket	25	0.0038

14. During aerobic cellular respiration, oxygen gas is consumed at the same rate as carbon dioxide gas is produced. In order to provide accurate volumetric measurements of oxygen gas consumption, the experimental setup should include which of the following?

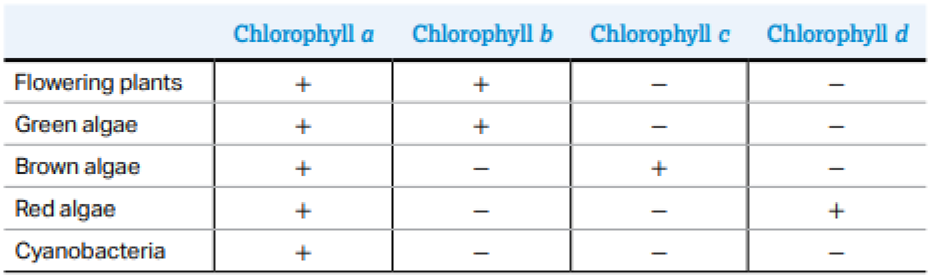
   a. A substance that removes carbon dioxide gas
   b. A plant to produce oxygen
   c. A glucose reserve
   d. A valve to release excess water

15. According to the data, the mice at 10°C demonstrated greater oxygen consumption per gram of tissue than did the mice at 25°C. This is most likely explained by which of the following statements?
    a. The mice at 10°C had a higher rate of ATP production than the mice at 25°C.
    b. The mice at 10°C had a lower metabolic rate than the mice at 25°C.
    c. The mice at 25°C weighed less than the mice at 10°C.
    d. The mice at 25°C were more active than the mice at 10°C.

Use the following information for question 16:

Different photosynthetic organisms have different types of chlorophyll molecules. The distribution of chlorophylls in several different groups of organisms is shown in Table 1. A plus sign (+) in the table indicates the presence of a chlorophyll, while a minus sign (-) indicates its absence.

Table 1. The distribution of chlorophylls in several groups of organisms



	Chlorophyll *a*	Chlorophyll *b*	Chlorophyll *c*	Chlorophyll *d*
Flowering plants	+	+	–	–
Green algae	+	+	–	–
Brown algae	+	–	+	–
Red algae	+	–	–	+
Cyanobacteria	+	–	–	–

16. Based on the data, which of the following most likely describes the evolutionary relationship among the organisms?
    a. Because brown algae, red algae, and cyanobacteria lack chlorophyll b, they evolved before green algae and flowering plants did.
    b. Because green algae and flowering plants contain chloroplasts, they evolved more recently than brown algae, red algae, and cyanobacteria did.
    c. Because increasingly complex forms of chlorophyll are found in red algae, brown algae, green algae, and flowering plants, respectively, this reflects the order of their appearance.
    d. Because all of the organisms contain chlorophyll a, the organisms share a common ancestor.

17. Experimental evidence shows that the process of glycolysis is present and virtually identical in organisms from all three domains, Archaea, Bacteria, and Eukarya. Which of the following hypotheses could be best supported by this evidence?
    a. All organisms carry out glycolysis in mitochondria.
    b. Glycolysis is a universal energy-releasing process and therefore suggests a common ancestor for all forms of life.
    c. Across the three domains, all organisms depend solely on the process of anaerobic respiration for ATP production.
    d. The presence of glycolysis as an energy- releasing process in all organisms suggests that convergent evolution occurred.

18. Where on an enzyme does the substrate bind?
    a. active site
    b. allosteric site
    c. C-terminus
    d. N-terminus

19. Describe the effect on the free energy of doubling the amount of enzyme.
   a. double the free energy
   b. half the free energy
   c. triple the free energy
   d. no effect on free energy

20. Which structure is unaffected by denaturation?
   a. Primary
   b. Secondary
   c. Tertiary
   d. Quaternary

21. Which environmental conditions can cause denaturation of the enzyme?
   a. slight increase in temperature
   b. extreme increase in temperature
   c. decrease in temperature
   d. extreme increase in temperature and pH changes

22. Which of the following will increase the rate of the reaction?
   a. increase product
   b. increase substrate
   c. increase inhibitor
   d. increase enzyme

23. Describe why an increase in temperature increases the rate of the reaction.
   a. increase in temperature increases the speed/kinetic energy of particles
   b. increase in temperature activates more enzyme to increase the rate
   c. increase in temperature results in increase in substrate available
   d. increase in temperature allows for a tighter fit in the active site

24. Describe the difference between competitive and noncompetitive inhibitors.
   a. noncompetitive binds to active site and competitive binds to other site
   b. competitive binds to active site and noncompetitive binds to other site
   c. competitive is irreversible and noncompetitive is reversible binding
   d. noncompetitive is irreversible and competitive is reversible binding

25. In order to maintain order and power cellular processes,
   a. energy input must exceed energy loss
   b. energy input equals energy loss
   c. energy loss must exceed energy input
   d. energy loss equals energy input

26. What is the process of an endergonic reaction being fueled by an exergonic reaction called?
   a. second law of thermodynamics
   b. energy coupling
   c. first law of thermodynamics
   d. endergonic/exergonic switch

27. Where did photosynthesis first evolve?
   a. prokaryotic organisms
   b. alien organisms
   c. eukaryotic organisms
   d. abiotic processes

28. What are the products of the light-dependent reactions of photosynthesis?
   a. ATP & NADH
   b. CO_2 & H_2O
   c. NADPH & ATP
   d. Organic Compounds & O_2

29. What is the function of the electron transport chain between Photosystem II and Photosystem I?
   a. establish electrochemical gradient of protons
   b. to funnel electrons into photosystem I for the Calvin cycle
   c. transport electrons to oxygen to make water
   d. to synthesize ATP using ATP synthase

30. Where does the Calvin cycle take place?
    a. thylakoid membrane
    b. cristae
    c. stroma
    d. matrix

31. Where does the electron transport chain take place?
    a. chloroplasts
    b. prokaryotic plasma membrane
    c. mitochondria
    d. all of the choices

32. Which of the following are electron carriers for the electron transport chain in cellular respiration?
    a. NADPH
    b. $FADH_2$
    c. NADH
    d. NADH & $FADH_2$

33. Which process releases energy in glucose to form ATP, NADH, and pyruvate?
    a. Glycolysis
    b. Oxidative Phosphorylation
    c. Krebs Cycle
    d. Fermentation

34. What is oxidation?
    a. loss of electrons
    b. loss of water
    c. gain of electrons
    d. gain of water

35. In the electron transport chain of cellular respiration, where is the electrochemical gradient of protons generated?
    a. cytosol
    b. cristae
    c. matrix
    d. intermembrane space

36. Which process does NOT require oxygen?
    a. Glycolysis
    b. Oxidative Phosphorylation
    c. Krebs Cycle
    d. Aerobic respiration

37. Describe the pathway of electrons in the light reactions.
    a. H_2O → PSI → ETC → PSII → NADPH
    b. H_2O → PSII → ETC → PSI → NADPH
    c. H_2O → PSII → ETC → PSI → NADH
    d. H_2O → PSI → ETC → PSII → NADH

38. Which of the following is the location for the light-dependent reactions?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

39. Which of the following is the location for the Krebs cycle?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

40. Which of the following is the location for the ATP synthesis in cellular respiration?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

41. Which of the following is the location for the ATP synthesis in photosynthesis?
    a. grana/thylakoid membrane
    b. matrix
    c. stroma
    d. cristae

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	D. At extremely low pH values, trypsin is denatured and cannot function efficiently	3.2	2020 CED
2	B. The light reactions of photosynthesis split water into hydrogen ions and oxygen.	3.4	2020 CED
3	B. How is ATP used in the formation of 3-carbon carbohydrates?	3.4	2013 #5
4	A. increased by exposure to light	3.4	2012 CED #13
5	C. yellow-leaved seedlings were unable to convert light energy to chemical energy	3.4	2012 CED #15
6	B. Comparing the observed results for sample 2 and sample 3	3.4*	2013 #41
7	D. Light from a lamp can substitute for sunlight in stimulating chloroplast processes	3.4*	2013 #42
8	C. The change in absorbance over time in the solution will be less than that of the other samples.	3.4*	2013 #43
9	A. Availability of electrons for transfer to DCPIP depends on light energy.	3.4*	2013 #44
10	B. What wavelength of light best activates electron transfer reactions in chloroplasts?	3.4*	2013 #45
11	D. Photosynthesis produces more oxygen than is consumed by respiration during the day.	3.4	2013 #17
12	B. During the light reactions of photosynthesis, water is split, removing electrons and protons, and oxygen gas is released.	3.4	2012 CED #36
13	B. Cellular respiration	3.5	2013 #47
14	A. A substance that removes carbon dioxide gas	3.5	2012 CED #8
15	A. The mice at 10°C had a higher rate of ATP production than the mice at 25°C.	3.5	2012 CED #9
16	D. Because all of the organisms contain chlorophyll a, the organisms share a common ancestor.	3.3	2020 CED #9
17	B. Glycolysis is a universal energy-releasing process and therefore suggests a common ancestor for all forms of life.	3.3	2012 CED #29
18	A. active site	3.1	Self
19	D. no effect on free energy	3.2	Self
20	A. Primary	3.2	Self
21	D. extreme increase in temperature and pH change	3.2	Self
22	D. increase enzyme	3.2	Self
23	A. increase in temperature increases the speed/kinetic energy of particles	3.2	Self
24	B. competitive binds to active site and noncompetitive binds to other site	3.2	Self
25	A. energy input must exceed energy loss	3.3	Self
26	B. energy coupling	3.3	Self
27	A. prokaryotic organisms	3.4	Self
28	C. NADPH & ATP	3.4	Self
29	A. establish electrochemical gradient of protons	3.4	Self
30	C. stroma	3.4	Self
31	D. all of the choices	3.4	Self
32	D. NADH & $FADH_2$	3.5	Self
33	A. Glycolysis	3.5	Self
34	A. loss of electrons	3.5	Self
35	D. intermembrane space	3.5	Self

36	A. Glycolysis	3.5	Self
37	B. H_2O → PSII → ETC → PSI → NADPH	3.5	Self
38	A. grana/thylakoid membrane	3.4	Self
39	B. matrix	3.5	Self
40	D. cristae	3.5	Self
41	A. grana/thylakoid membrane	3.4	Self

* no longer in AP Classroom so might be "out of scope"

Multiple Choice Explanations

Q		Explanation:
1	A	The prompt nor figure give information about an inhibitor released by the small intestines.
	B	pH does not affect the collisions of enzyme and substrate. When temperature is increased, there is an increase in collision as there is an increase in kinetic enzyme from the heat energy.
	C	pH does not affect substrate concentration. In addition, there is no information given in the prompt nor figure about substrate concentration.
	D	**A change in pH outside of an enzyme optimal range will affect the bonding patterns. This change in bonding affects the structure of the enzyme which affects the function of the enzyme. The figure shows the maximum activity at pH ~8 with a drastic decrease moving towards the low pHs demonstrating this reduction in activity due to denaturation.**
2	A	The light reactions do not involve carbon dioxide. In addition, carbon dioxide is fixed in the Calvin cycle of photosynthesis and is not broken down to release oxygen.
	B	**The light reactions involve the process of photolysis which using solar energy to break a water molecule into hydrogen and oxygen.**
	C	The Calvin cycle fixes carbon dioxide to synthesize carbohydrates like G3P which is used to make glucose (not break it down releasing oxygen).
	D	The Calvin cycle does not use water nor does it release oxygen.
3	A	Chlorophyll capturing light involves the light reactions not the Cavin cycle.
	B	**The Calvin cycle results in the formation of a G3P molecule which is a 3-carbon carbohydrate.**
	C	$NADP^+$ is reduced to NADPH during the light reactions not the Calvin cycle.
	D	ATP is produced by chemiosmosis during the light reactions not the Calvin cycle.
4	A	**As seen by the germinated seeds, there are 12 in the covered dish A and 20 in the uncovered dish A. This shows that exposure of light increases the germination of the seeds.** **This option is correct. Dish B, which was uncovered, had 20 seeds germinate, while the covered dish A had only 12 seeds germinate in the first week. (CollegeBoard)**
	B	The light intensity is not differed in this experimental design. There is a covered and uncovered which shows that covered has less germination than uncovered. This option is incorrect because the only variable was light intensity, and dish B did have more seeds germinate when exposed to light versus only 12 seeds in dish A, which was not exposed to light. (CollegeBoard)
	C	The paper towels constant and are moistened then placed into petri dishes for seeds (not wrapped around the seeds inhibiting light exposure). This option is incorrect because both dishes had paper towels — the paper towels were a controlled variable (CollegeBoard)
	D	The seedlings succeed the germinated seeds so the color of the seeds has no impact on the germination of the seeds. This option is incorrect. Germination occurred more rapidly in the yellow-leaved seedlings in dish A and at the same rate in dish B, so the data do not support the claim that germination was accelerated in green-leaved seedlings. (CollegeBoard)
5	A	The color of the leaf has no impact on the ability for the roots to absorb water. This option is incorrect because there is no evidence that yellow seedlings were unable to absorb water between days 14–21. In addition, because the seedlings were capable of doing so during the first 14

		days, there is no evidence to support this claim that they could not absorb water after day 14. (CollegeBoard)
	B	The reduced light would lead to less photosynthesis not This option is incorrect because there is no evidence that green seedlings were taller (CollegeBoard)
	C	**Leaves are traditionally green since they absorb all colors except for green. If the leaves are yellow, the plant is unable to absorb the light energy and convert to chemical energy. This absence of chemical energy reduces the amount of energy for the plant which can lead to dead.** **This option is correct. The only difference between the two plants after day 14 was the leaf color. Without chlorophyll, the yellow seedlings could not absorb enough light energy to convert to chemical energy to sustain growth. Therefore, no yellow seedlings were found alive in either dish after day 21. (CollegeBoard)**
	D	There is no additional respiration need for the yellow-leaved seedling over the green-leaved seedlings. This option is incorrect because there are no data supporting a higher rate of respiration in yellow seedlings compared to green seedlings (CollegeBoard)
6	A	Calculating the rate of change in absorbance explains how light affects only Sample 1, but there was no comparison to the other samples.
	B	**Samples 2 and 3 are both 30 cm away from the lamp. Sample 2 is uncovered and sample 3 is covered, so you would be able to determine the requirement of light for electron transfer.**
	C	There is still light at night. In addition, you would not be able to maintain the experimental procedure at night.
	D	Increasing the trials will give you more information about the samples you already have. The two samples that allow you to determine light requirement is Samples 2 and 3 as all conditions remain the same except the presence or absence of light.
7	A	All of the samples were suspended, but sample 3 did not demonstrate the same level of absorbance as observed by sample 2 at the same distance (nor did it fit with the trend of increasing distance and absorbance)
	B	All of the samples were at room temperature, so there shouldn't be a difference due to temperature of the experiment.
	C	If the biochemical processes were inhibited, there would be no data obtained regarding the changing of the DCPIP solution as it gains electrons from the light reactions.
	D	**Since the light came from the lamp and was able to produce the absorbance difference, it showed the lamp could be a substitute for sunlight.**
8	A	The DCPIP is being used as an electron acceptor. It will be added to the sample so the concentration will be the same as the other samples.
	B	The absorbance of 75 cm is 0.56 and 60 cm is 0.41, so you would not expect the 90 cm to be 1.4. In addition, I do not believe you can have an absorbance greater than 1.
	C	**The absorbance of 75 cm is 0.56, 60 cm is 0.41, and 45 is 0.26. The amount of absorption will be greater than 0.56.**
	D	The temperature remains constant in the experimental design.
9	A	**The absorbance decreases the closer the light source gets to the sample. This demonstrates that the light energy has an impact on the amount of electrons released which means it has an effect on photosynthesis.**
	B	DCPIP is an electron acceptor and does not pass across the membrane. The absorbance data comes from the solution becomes more colorless as it accepts electrons.

	C	Chlorophyll is the site of light absorbance which results in the electrons being donated. As electrons are accepted by the DCPIP, the solution will change color. Since the absorbance changed, the chlorophyll does not degrade the DCPIP
	D	DCPIP was used throughout the entire experiment up to 75 cm recorded.
10	A	This experiment does not measure carbon dioxide, thus it would not be an appropriate investigation with this set-up.
	B	**The experiment can be set-up in the same fashion except instead of different distances, it would be different wavelengths. This would provide quantitative data regarding how the wavelength affects the electrons generated.**
	C	This experiment does not investigate the components of photosynthesis to determine the molecule that accepts the activated electrons. In addition, the answer states the electrons are coming from the DCPIP which is opposite of the prompt.
	D	This experiment does not investigate gene expression.
11	A	Colder water does increase the amount of gas that can be held by a solution, but the figure shows that at night the concentration of oxygen steadily decreases.
	B	Does it? I would think that it decreases as most organisms are diurnal (awake during the daytime and sleep at night).
	C	The same number of organisms are present during the day and at night, so there wouldn't be more organisms respirating.
	D	**The figure shows the difference between hours of light and hours of darkness. During the light, the graph increases and during the darkness the graph decreases. Photosynthesis will use the light to synthesize G3P with a byproduct of oxygen. At night, the plants are no longer producing the oxygen as a byproduct so the concentration decreases.**
12	A	Carbon dioxide is not used during the light reactions. The light reactions involve absorbing the light energy and storing the energy in ATP and removing the electrons from water and storing in NADPH. The ATP and NADPH has future usage in the Calvin cycle. This option is incorrect because carbon dioxide fixation is not part of the light-dependent reactions. (CollegeBoard)
	B	**During the light reactions, the water is split using light energy to break a water molecule (photolysis) which removes electrons donating to the reaction center complex. The oxygen gas is released.** **This option is correct. This choice correctly describes the events of the light dependent reactions and indicates that the student can justify the selection of data regarding the types of molecules that an organism will take up as necessary building blocks. (CollegeBoard)**
	C	Water is not split during the Calvin cycle. The Calvin cycle uses the ATP and NADPH from the light reactions to fix carbon from carbon dioxide in the form of carbohydrates. NADPH is oxidized to make $NADP^+$ but no oxygen is released. This option is incorrect because water is not split in the Calvin cycle. (CollegeBoard)
	D	Water is not split during the Calvin cycle. The Calvin cycle uses the ATP and NADPH from the light reactions to fix carbon dioxide in the form of carbohydrates. This option is incorrect because water is not split in the Calvin cycle (CollegeBoard)
13	A	All of these organisms are surrounded by water and will not lose water to evaporation.
	B	**None of the organisms were provided with nutrients. All three organisms require ATP and thus undergo cellular respiration to make the ATP which reduces their mass as fuel is converted to carbon dioxide and water.**

	C	Law of conservation of matter is not demonstrated by this table as we only see the decrease in mass. There is no record of the gaseous components that could have been tested as well.
	D	Without nutrients, the organism is probably not able to grow or reproduce. Thus the mass decrease is not due to solely the growth and reproduction of two organisms.
14	A	**If you did the cellular respiration respirometer lab, then you knew this information without looking into the question, KOH was used to bind to the carbon dioxide to remove it from the tube which decreases the pressure within the tube allowing the water to move up the pipette to allow for quantitative data regarding the volume of oxygen consumed.** **This option is correct. There is no change in gas volume measured by the respirometer unless carbon dioxide is removed, because oxygen is consumed at the same rate that carbon dioxide is produced during cellular respiration (CollegeBoard)**
	B	If the plant is producing oxygen, you will be unable to determine the amount of oxygen consumed by the mouse or cricket. This option is incorrect because the production of oxygen by plants is by the process of photosynthesis, which is not the focus of this experiment. The focus of this experiment is the consumption of oxygen during aerobic cellular respiration, not the production of oxygen gas during photosynthesis. (CollegeBoard)
	C	A glucose reserve will allow for the starting material of cellular respiration. This is a solid and the oxygen is a gas, so this will not allow you to determine the oxygen consumed. This option is incorrect because a glucose reserve would have no effect on the measurement of oxygen gas consumption because the oxidation of glucose via aerobic cellular respiration would still consume oxygen gas at the same rate as carbon dioxide production (CollegeBoard)
	D	The water is used to measure the oxygen consumption. As the organism consumes the oxygen and releases the carbon dioxide, there will an even exchange of gases so no change in the pressure which means the water level will not enter the tube. This option is incorrect because the release of excess water would have no effect on the relative volumes of oxygen or carbon dioxide gas. There would not be enough water produced in this experiment to affect gas volume due to differences in solubility. (CollegeBoard)
15	A	**The process of cellular respiration produces heat as a byproduct, Endothermic organisms will perform cellular respiration at a higher rate in colder conditions to maintain their body temperature.** **This option is correct. Mice are endotherms and at cold temperatures will increase their rate of ATP production in order to shiver. This increase in metabolism will produce heat according to the second law of thermodynamics. This heat production will help the mouse maintain a constant internal environment. (CollegeBoard)**
	B	A lower metabolic rate means there will be less cellular respiration performed. According to the data table, there is a greater oxygen consumption at colder temperatures. A greater oxygen consumption means that there is an higher rate of cellular respiration. This option is incorrect because a lower metabolic rate would mean a lower consumption of oxygen. The data do not support this claim. The mouse consumed more oxygen at 10°C than at 25°C(CollegeBoard)
	C	There is a relationship between metabolic rate per unit body mass and the size of multicellular organisms—generally, the smaller the organism, the higher the metabolic rate. (ENE-1.M.1) The 25°C mice had a lower rate of oxygen consumption so it didn't weigh less than the 10°C mice.

		This option is incorrect because the data for oxygen consumption were controlled for by mass / weight. All numbers are mL/g (CollegeBoard)
	D	An increase in activity means an increase in metabolism/cellular respiration. If there is an increase in cellular respiration, there is an increase in oxygen consumption. The 25°C mice had a lower rate of oxygen consumption then 10°C mice. This option is incorrect because the data do not support this claim. If the mice were more active at the higher temperature, then they would have consumed more oxygen. More activity would require more ATP, which is produced by aerobic cellular respiration in mice. (CollegeBoard)
16	A	There is no evidence to support this. The brown algae has chlorophyll c while others do not, red algae has chlorophyll d while others do not, and cyanobacteria has no additional chlorophyll aside from chlorophyll a.
	B	The information about which organisms contained chloroplasts was not given in this data set.
	C	Although the type of chlorophyll varies between these organisms, there is no consistency. In order to "gain" a trait, they all "lose" a trait which does not represent an order of appearance. The traits would be building upon one another if demonstrating order of appearance.
	D	**This would be considered an ancestral trait. All of the organisms have this trait before their common ancestor had the trait.**
17	A	Glycolysis takes place in the cytosol which is why it is able to be found in prokaryotes and eukaryotes. This option is incorrect. Glycolysis does not occur in the mitochondria. Archaea and Bacteria do not contain mitochondria (CollegeBoard)
	B	**All organisms are able to undergo glycolysis demonstrating that it is an ancestral trait from a common ancestor.** **This option is correct because it demonstrates understanding of the processes of evolution and glycolysis, which is common to both aerobic and anaerobic respiration (CollegeBoard)**
	C	Aerobic respiration provides more ATP so most organisms depend on aerobic respiration for ATP production. This option is incorrect. Many organisms rely on aerobic respiration for ATP production. (CollegeBoard)
	D	Convergent evolution does not show common ancestry. Convergent evolution is a similar solution to a similar problem. This option is incorrect. There is no evidence for any other energy-producing process that substitutes for and predates glycolysis (CollegeBoard)
18	A	**The structure of enzymes includes the active site that specifically interacts with substrate molecules. (ENE-1.D.1)**
	B	Allosteric site is another site on the enzyme for regulation of enzyme activity. Activators can bind to lock the active site into position or inhibitors can bind to change the shape of active site inhibiting binding.
	C	The C-terminus is the carboxyl end of the polypeptide.
	D	The N-terminus is the amine end of the polypeptide.
19	A	Enzymes do not affect the Gibbs free energy. Enzymes only lower activation energy.
	B	Enzymes do not affect the Gibbs free energy. Enzymes only lower activation energy.
	C	Enzymes do not affect the Gibbs free energy. Enzymes only lower activation energy.
	D	**Enzymes are biological catalysts that facilitate chemical reactions in cells by lowering the activation energy. (ENE-1.E.1) This decrease of activation does not affect the Gibbs free energy**

		and the free energy is the same between an enzyme-catalyzed reaction and a non-catalyzed reaction.
20	A	**Primary structure is the string of amino acids held together by peptide bonds. The denaturation process does not break the peptide bonds between amino acids. I like to think of denaturation as an unraveling.**
	B	Secondary structure is the alpha helix and beta pleated sheets held together by hydrogen bonds between the backbone of the polypeptide. The hydrogen bonds are weak bonds that can easily be broken (and are broken when the protein denatures).
	C	Tertiary structure is the final three-dimensional structure of a polypeptide held together by any bond between the R groups of the polypeptide. These bonds are broken when the protein denatures.
	D	Quaternary structure is the structure formed when multiple three-dimensional polypeptides bind forming the overall structure of the protein. These bonds are broken when the protein denatures.
21	A	A slight increase in temperature will cause an increase in reaction rate as the heat energy causes an increase in kinetic energy which increases the rate of collisions and the energy of collisions allowing the reactants to overcome the activation energy.
	B	This is a correct statement. The extreme temperature increase strains the bonds as the atoms move faster due to the heat energy.
	C	A decrease in temperature will cause a decrease in reaction rate as the atoms move slower.
	D	**The extreme temperature increase strains the bonds as the atoms move faster due to the heat energy. The pH changes cause changes in the bonding of the polypeptide which causes it to denature.**
22	A	If there is more product, it will cause product inhibition where the product binds to the active site inhibiting the enzyme. This will decrease the rate of the reaction.
	B	If you increase the substrate, there is more starting materials for the reaction. BUT, if the enzyme is already saturated, adding more substrate does not make the enzyme work faster.
	C	If there is an inhibitor, it will bind to the enzyme to compete for the active site with the substrate or it will change the shape of the active site to decrease binding with the substate.
	D	**If you increase the enzyme, there are twice as many "workers" so the reaction can proceed twice as fast.**
23	A	**Higher environmental temperatures increase the speed of movement of molecules in a solution, increasing the frequency of collisions between enzymes and substrates and therefore increasing the rate of reaction (ENE-1.G.3)**
	B	The prompt does not mention that there is an enzyme present. The increase in temperature provides environmental energy that can be used for activation energy.
	C	Temperature cannot cause there to be more starting material for a reaction.
	D	The active site and the changes to the active site are due to molecular interactions from bonding with the substrate.
24	A	Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme (ENE-1.G.4).
	B	**Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme (ENE-1.G.4).**
	C	Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme (ENE-1.G.4).
	D	Competitive inhibitor molecules can bind reversibly or irreversibly to the active site of the enzyme. Noncompetitive inhibitors can bind allosteric sites, changing the activity of the enzyme (ENE-1.G.4).

25	A	**Life requires a highly ordered system and does not violate the second law of thermodynamics—a. Energy input must exceed energy loss to maintain order and to power cellular processes (ENE-1.H.2)**
	B	If the energy input equals the energy loss then it does not follow the second law of thermodynamics.
	C	If the energy loss exceeds energy input, then there isn't enough energy for the processes. Loss of order or energy flow results in death (ENE-1.H.2)
	D	If the energy loss equals the energy input then it does not follow the second law of thermodynamics.
26	A	The second law of thermodynamics states that every energy transfer or transformation increases the entropy of the universe. Usable forms of energy are at least partly converted to heat.
	B	**Energy coupling is a term from cellular metabolism, the use of energy released from an exergonic reaction to drive an endergonic reaction.**
	C	The first law of thermodynamics is the principle of conservation of energy. It refers to energy is able to be transferred and transformed, but it cannot be created or destroyed.
	D	I made this up – so I don't think there is anything with this name. Endergonic reactions absorb energy. Exergonic reactions are reactions that release free energy.
27	A	**Photosynthesis first evolved in prokaryotic organisms. (ENE-1.I.1)**
	B	Oh… you believe in aliens? Kidding – I don't think anyone is reading this so I hope you having a great day. I don't believe there has been evidence of alien photosynthetic organisms transported to Earth.
	C	There are photosynthetic prokaryotes. Evolutionarily eukaryotes diverged from prokaryotes after an endosymbiotic event. The chloroplast is believed to be a prokaryote in a symbiotic relationship with photosynthetic eukaryotes.
	D	Photosynthesis has not been determined to be able to be completed without a living form (abiotically).
28	A	ATP is synthesized during the light reactions to drive the Calvin cycle, but NADH is found in cellular respiration not photosynthesis.
	B	Carbon dioxide is reactant in the Calvin cycle. Water is reactant in the light reactions.
	C	**The light-dependent reactions of photosynthesis in eukaryotes involve a series of coordinated reaction pathways that capture energy present in light to yield ATP and NADPH, which power the production of organic molecules (ENE-1.I.2)**
	D	Organic compounds (specifically G3P) are the products of the Calvin cycle. O_2 is a product of the light reactions.
29	A	**When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) is established across the internal membrane. (ENE-1.J.3)**
	B	The electrons are carried to the Calvin cycle with NADPH. The electrons from photosystem II do funnel into photosystem I after the electron transport chain to replace those lost by photosystem I.
	C	Electrons are released from water during a process of photolysis in photosystem II. The oxygen binding with the electrons to make water describes the process at the end of the electron transport chain in cellular respiration.
	D	The electron transport chain does not synthesize ATP. The ATP is synthesized due to the protons flowing down their concentration gradient (exergonic) to provide the energy to the phosphorylation of ADP reaction (endergonic).
30	A	The light reactions take place in the thylakoid membrane.
	B	The electron transport chain of cellular respiration takes place in the cristae.
	C	**Calvin cycle occurs in the stroma of the chloroplast (ENE-1.J.5)**
	D	The Krebs cycle of cellular respiration takes place in the mitochondrial matrix.
31	A	The ETC takes place in the thylakoid membrane during the light reactions of photosynthesis.
	B	The ETC takes place in the plasma membrane in prokaryotes.
	C	The ETC takes place in the cristae during oxidative phosphorylation of cellular respiration.

	D	**The electron transport chain transfers energy from electrons in a series of coupled reactions that establish an electrochemical gradient across membranes— (a) Electron transport chain reactions occur in chloroplasts, mitochondria, and prokaryotic plasma membranes. (ENE-1.K.3)**
32	A	NADPH is the electron carrier in photosynthesis to carry the electrons from the light reactions to the Calvin cycle.
	B	$FADH_2$ is an electron carrier in cellular respiration reduced during the Krebs cycle.
	C	NADH is the electron carrier in cellular respiration reduced during glycolysis, pyruvate oxidation, and Krebs cycle.
	D	**(b) In cellular respiration, electrons delivered by NADH and $FADH_2$ are passed to a series of electron acceptors as they move toward the terminal electron acceptor, oxygen. (ENE-1.K.3)**
33	A	**Glycolysis is a biochemical pathway that releases energy in glucose to form ATP from ADP and inorganic phosphate, NADH from NAD^+, and pyruvate (ENE-1.L.1)**
	B	Oxidative phosphorylation involves electron transport chain oxidizing NADH and $FADH_2$ and generating a proton gradient ending with oxygen making water. The proton gradient is used to synthesize ATP.
	C	In the Krebs cycle, carbon dioxide is released from organic intermediates, ATP is synthesized from ADP and inorganic phosphate, and electrons are transferred to the coenzymes NADH and $FADH_2$. (ENE-1.L.3)
	D	Fermentation is the process that succeeds glycolysis to allow the cell to continue breaking down glucose and synthesizing ATP in the absence of oxygen.
34	A	**OIL RIG – Oxidation is loss (of electrons), Reduction is gain (of electrons). These two terms are matched because if something is oxidized, there's also something reduced. Simple example: Sodium atom is oxidized by Chloride atom. The sodium loses its valence electron making sodium ion and the chloride gains the electron making chloride ion.**
	B	Dehydration involves a loss of water to form a bond between monomers.
	C	This is backwards. Oxidation is loss of electrons and reduction is gain of electrons.
	D	Hydrolysis involves the use of water to break a bond between monomers.
35	A	The cytosol is too large of a space. In addition, the electron transport chain is located on the inner mitochondrial membrane so the protons would need to be moved the inner mitochondrial membrane AND the membrane of the mitochondria.
	B	The cristae is the inner mitochondrial membrane. The protons are not stored in the interior of the membrane.
	C	The matrix is located in the innermost portion of the mitochondria. This is a logical choice as the protons are pumped across the inner mitochondrial membrane, but the protons are pumped OUT into the intermembrane space.
	D	**When electrons are transferred between molecules in a sequence of reactions as they pass through the ETC, an electrochemical gradient of protons (hydrogen ions) across the inner mitochondrial membrane is established. (ENE-1.L.5)**
36	A	**Glycolysis takes place in the cytosol and does not require oxygen. NADH is able to be oxidized by fermentation in the absence of oxygen.**
	B	Oxidative phosphorylation requires oxygen as the oxygen is the final electron acceptor in the electron transport chain.
	C	Krebs cycle as an independent step does not involve oxygen, but the NADH and $FADH_2$ will be unable to be oxidized without the electron transport chain which requires oxygen.
	D	Aerobic respiration by definition requires oxygen. "It is the process of cellular respiration that takes place in the presence of oxygen gas to produce energy from food"
37	A	The first photosystem is II not photosystem I. Super easy mistake! Keep smiling penguin.
	B	**Water is the source of electrons. As the water is split by photolysis, the electrons are released. These electrons will replace the lost electrons from photosystem II. The electrons go through an**

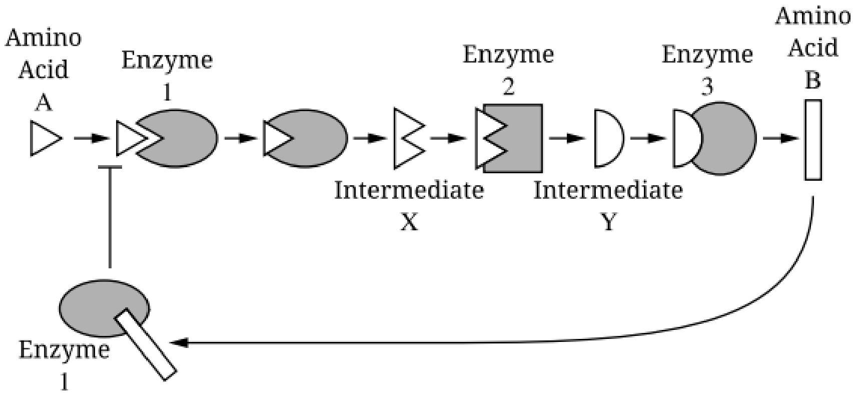
		electron transport chain and replace the lost electrons from photosystem I. The electrons are used to reduce NADP$^+$ to carry the electrons to the Calvin cycle from the light reactions.
	C	NADH is found in cellular respiration while NADPH is found in photosynthesis. Super easy mistake! Keep smiling penguin.
	D	The first photosystem is II not photosystem I. NADH is found in cellular respiration while NADPH is found in photosynthesis. Super easy mistakes! Keep smiling penguin.
38	A	**The light-dependent reactions of photosynthesis occur in the grana (SYI-1.F.5)**
	B	The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria. (SYI-1.F.8)
	C	The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid. (SYI-1.F.6)
	D	Electron transport and ATP synthesis occur on the inner mitochondrial membrane. (SYI-1.F.9)
39	A	The light-dependent reactions of photosynthesis occur in the grana (SYI-1.F.5)
	B	**The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria. (SYI-1.F.8)**
	C	The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid. (SYI-1.F.6)
	D	Electron transport and ATP synthesis occur on the inner mitochondrial membrane. (SYI-1.F.9)
40	A	The light-dependent reactions of photosynthesis occur in the grana. (SYI-1.F.5)
	B	The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria. (SYI-1.F.8)
	C	The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid. (SYI-1.F.6)
	D	**Electron transport and ATP synthesis occur on the inner mitochondrial membrane. (SYI-1.F.9)**
41	A	**The light-dependent reactions of photosynthesis occur in the grana. (SYI-1.F.5) ATP is synthesized during the light dependent reactions in photosynthesis.**
	B	The Krebs cycle (citric acid cycle) reactions occur in the matrix of the mitochondria. (SYI-1.F.8). ATP is synthesized during glycolysis, Krebs cycle, and oxidative Phosphorylation in cellular respiration.
	C	The stroma is the fluid within the inner chloroplast membrane and outside of the thylakoid. (SYI-1.F.6). ATP is used during the Calvin cycle located in the stroma during photosynthesis.
	D	Electron transport and ATP synthesis occur on the inner mitochondrial membrane. (SYI-1.F.9) during cellular respiration.

Free Response Practice

2025 #5

Figure 1 shows the reactions of the metabolic pathway used to synthesize amino acid B from amino acid A in cells.

Figure 1. Synthesis of amino acid B from amino acid A



(a) **Describe** a characteristic of an enzyme's active site that allows it to catalyze a specific chemical reaction.
(b) Based on Figure 1, **explain** how the binding of amino acid A to enzyme 1 is regulated by amino acid B.
(c) Using the information in Figure 1, **identify** the product of the reaction catalyzed by enzyme 2: intermediate X, intermediate Y, or amino acid B.
(d) Based on Figure 1, **explain** how a change in pH could affect enzyme 3 in such a way that amino acid B cannot be produced.

2024 #2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

a) **Describe** the role of water in the hydrolysis of ATP.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\,\mathrm{SE}_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\,\mathrm{SE}_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

b)

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25 C° .

c)

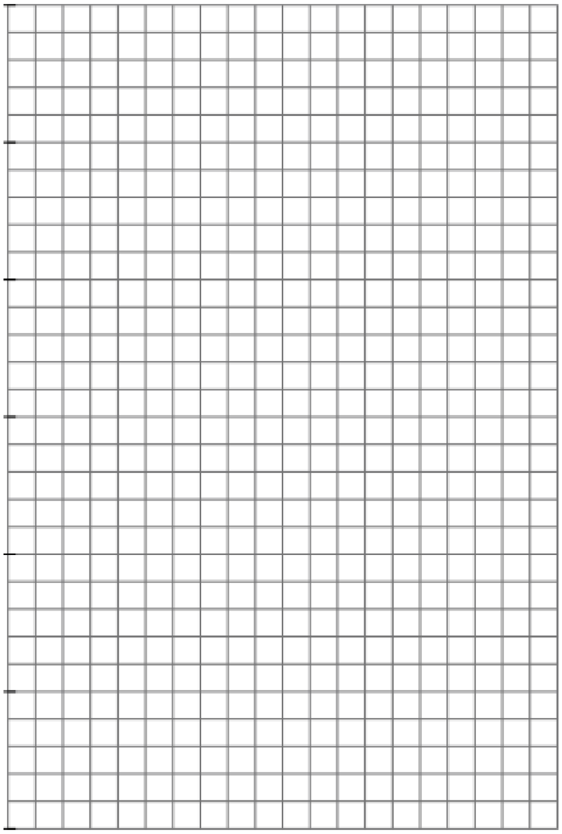
i. Based on the data in Table 1, **describe** the effect of temperature on the rate of ATP synthesis in liver cells from toads.

ii. Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25 C° .

d)

i. Oligomycin is a compound that can block the channel protein function of ATP synthase. **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane.

ii. **Justify** your prediction



2023 #4

Noncyclic electron flow and cyclic electron flow are two major pathways of the light-dependent reactions of photosynthesis. In noncyclic electron flow, electrons pass through photosystem II, then components of a chloroplast electron transport chain, and then photosystem I before finally reducing $NADP^+$ to NADPH.. In cyclic electron flow, electrons cycle through photosystem I and some components of the electron transport chain (Figure 1).

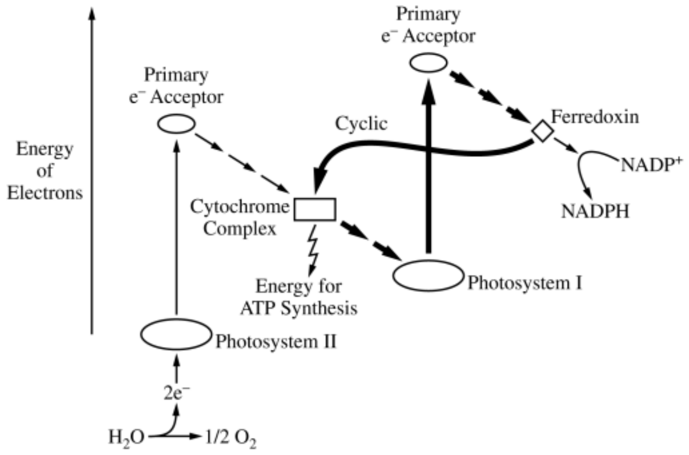


Figure 1. The pathways of noncyclic and cyclic (heavy arrows) electron flow. The cytochrome complex is a component of the electron transport chain between the two photosystems.

(a) **Describe** the role of chlorophyll in the photosystems of plant cells.

(b) Based on Figure 1, **explain** why an increase in the ratio of NADPH to $NADP^+$ will cause an increase in the flow of electrons through the cyclic pathway.

(c) Using rice plants, scientists examined the effect of a mutation that results in the loss of the protein CRR6. CRR6 is a part of the photosystem I complex, and its absence reduces the activity of photosystem I. **Predict** the effect of the mutation on the rate of biomass (dry weight) accumulation.

(d) **Justify** your prediction in part (c).

2022 #3

Fireflies emit light when the enzyme luciferase catalyzes a reaction in which its substrate, D-luciferin, reacts to form oxyluciferin and other products (Figure 1). In order to determine the optimal temperature for this enzyme, scientists added ATP to a solution containing D-luciferin, luciferase, and other substances needed for the reaction. They then measured the amount of light emitted during the first three seconds of the reaction when it was carried out at different temperatures.

$$\text{D-Luciferin} + O_2 + \text{ATP} \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + CO_2 + \text{AMP} + PP_i + \text{Light}$$

Figure 1. Light is emitted as a result of the reaction catalyzed by luciferase.

(a) **Describe** a characteristic of the luciferase enzyme that allows it to catalyze the reaction.

(b) **Identify** the dependent variable in the experiment.

(c) **State** the null hypothesis for the experiment.

(d) A student claims that, as temperature increases, there will be an increase in the amount of light given off by the reaction in the first three seconds. **Support** the student's claim.

2021 #3

Researchers hypothesize that the plant compound resveratrol improves mitochondrial function. To test this hypothesis, researchers dissolve resveratrol in dimethyl sulfoxide (DMSO). The solution readily passes through cell membranes. They add resveratrol solution to mammalian muscle cells growing in a nutrient-rich solution (culture medium) that contains glucose. They measure ATP production at several time points after the addition of the resveratrol solution and find an increase in ATP production by the muscle cells.

(a) **Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation.

(b) **Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment.

(c) **Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars.

(d) The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** this claim.

2019 #3

This question is in Unit 5.

2019 #7

This question is in Unit 6.

2017 #1

This question is in Unit 8.

2017 #5

Microcystis aeruginosis is a freshwater photosynthetic cyanobacterium. When temperatures increase and nutrients are readily available in its pond habitat, M. aeruginosis undergoes rapid cell division and forms an extremely large, visible mass of cells called an algal bloom. M. aeruginosis has a short life span and is decomposed by aerobic bacteria and fungi. Identify the metabolic pathway and the organism that is primarily responsible for the change in oxygen level in the pond between time I and II AND between times III and IV.

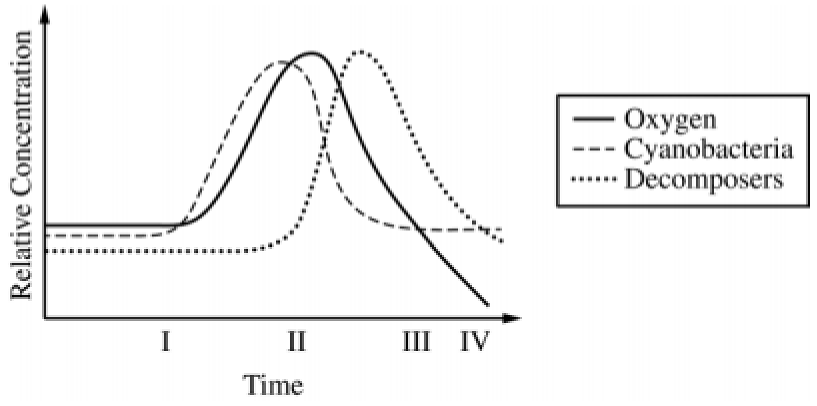


Figure 1. Characteristics of a pond community over time

2017 #7

Many species of bacteria grow in the mouths of animals and can form biofilms on teeth (plaque). Within plaque, the outer layers contain high levels of oxygen and the layers closest to the tooth contain low levels of oxygen. The surface of the tooth is covered in a hard layer of enamel, which can be dissolved under acidic conditions. When the enamel breaks down, the bacteria in plaque can extract nutrients from the tooth and cause cavities.
Certain types of bacteria (e.g. *Streptococcus mutans*) thrive in the innermost anaerobic layers of the plaque and are associated with cavities. Other types of bacteria (*Streptococcus sanguinis*) compete with *S. mutans* but are unable to thrive in acidic environments.

(a) **Identify** the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque.

(b) Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth, but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used.

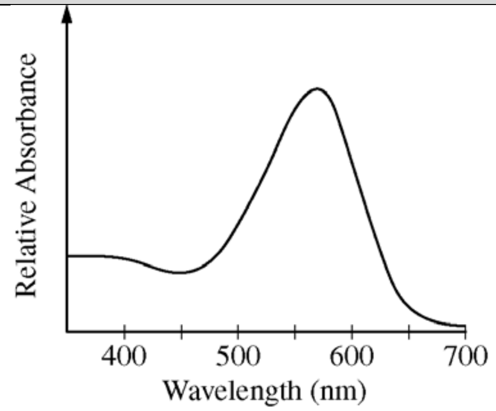
2016 #3

This question is in Unit 8.

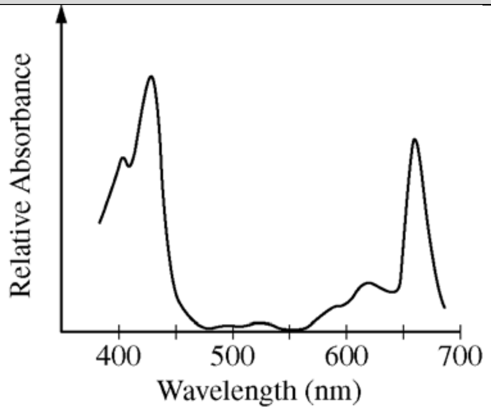
2015 #2

This question is in Unit 7.

2013 #2



Graph I



Graph II

Color	Wavelength (nm)
Violet	380 – 450
Blue	450 – 475
Cyan	475 – 495
Green	495 – 570
Yellow	570 – 590
Orange	590 – 620
Red	620 - 750

An absorption spectrum indicates the relative amount of light absorbed across a range of wavelengths. The graphs above represent the absorption spectra of individual pigments isolated from two different organisms. One of the pigments is chlorophyll a, commonly found in green plants. The other pigment is bacteriorhodopsin, commonly found in purple photosynthetic bacteria. The table above shows the approximate ranges of wavelengths of different colors in the visible light spectrum.

(a) **Identify** the pigment (chlorophyll a or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer.

(b) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions.

(c) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum.

2013 #4
This question is in Unit 8.

Free Response Scoring Guidelines

2025 #5

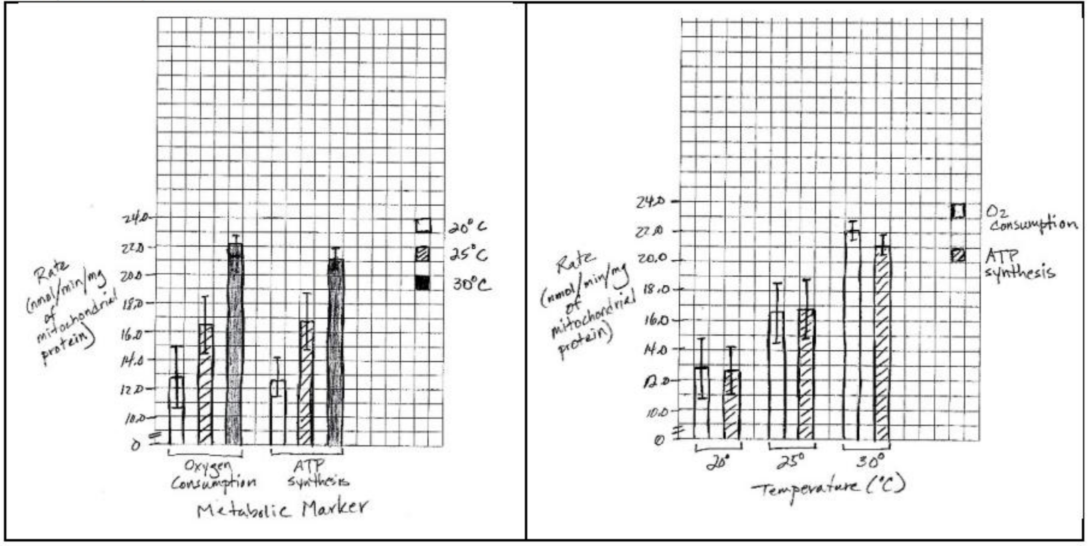
Course Content	Practice and Skill
3.1: Enzymes • 3.1.A*: Explain how enzymes affect the rate of biological reactions. 3.2: Environmental Impacts on Enzyme Function • 3.2.A*: Explain how changes to the structure of an enzyme may affect its function. • 3.2.B*: Explain how the cellular environment affects enzyme activity.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 2D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

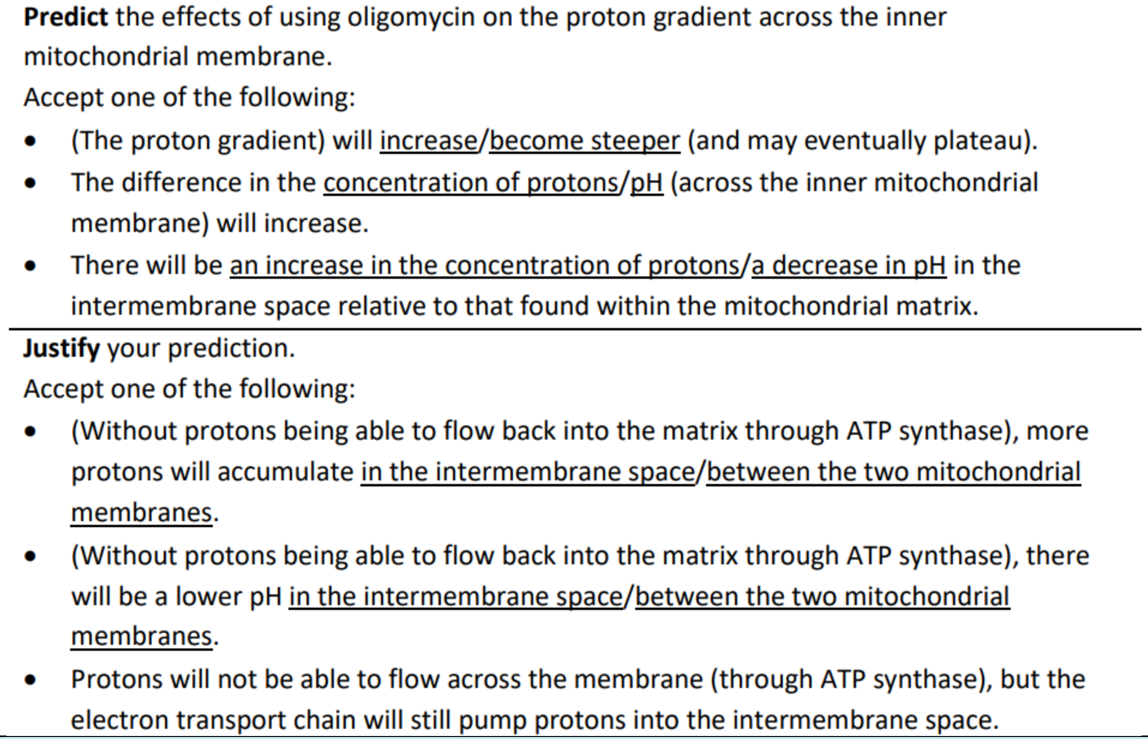
Part	Scoring Guidelines
(a)	Examples of acceptable responses may include the following: • (The active site) is able to bind to a (specific) substrate/amino acid. • The shape/charge of the active site of an enzyme is compatible with a (specific) substrate/amino acid. • (The active site) positions the substrate/amino acid in a way that makes the reaction more likely. • Induced fit stresses bonds so that a reaction is more likely to occur.
(b)	Examples of acceptable responses may include the following: • Amino acid B inhibits the binding of amino acid A to enzyme 1. • Amino acid B binds to an allosteric site of enzyme 1 and prevents amino acid A from binding to enzyme 1. • The binding of amino acid B causes the enzyme to change shape and prevents amino acid A from binding to enzyme 1.
(c)	• (Intermediate) Y
(d)	Examples of acceptable responses may include the following: • (A change in pH) could change the structure/active site/enzyme so that intermediate Y/the substrate cannot bind. • (A change in pH) could denature (enzyme 3) so that intermediate Y/the substrate cannot bind.

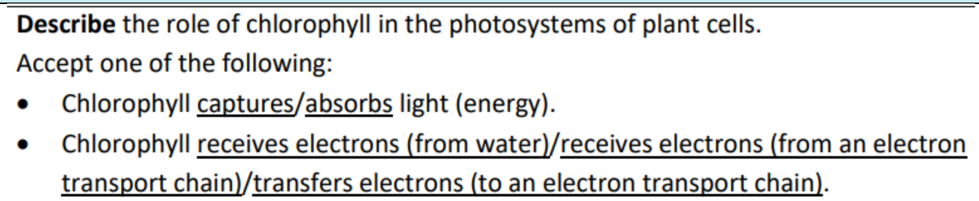
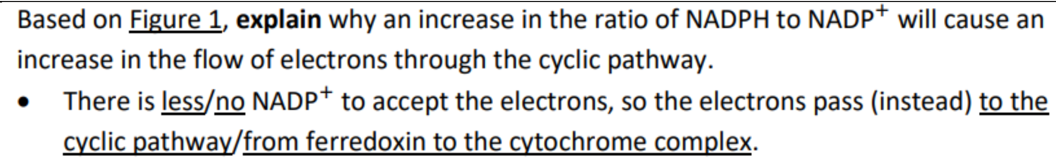
	Max Points:	**Mean Score:**
Part A	1.0	0.55
Part B	1.0	0.37
Part C	1.0	0.72
Part D	1.0	0.36

Overall Mean Score: 2.00

2024 #2	
Course Content	**Practice and Skill**
1.3: Introduction to Macromolecules - 1.3.A: Describe the chemical reactions that build and break biological macromolecules. 3.5: Cellular Respiration - 3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.	1.A: Describe biological concepts and processes. 4.A: Construct a graph to represent the data 4.B: Describe data from a table or graph 5.A 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	**Describe** the role of water in the hydrolysis of ATP. Accept one of the following: - Water is added in the process of cleaving/splitting (a phosphate from) ATP. - Water breaks down/splits ATP.
(b)	Sample Responses:  - Data are represented in a bar graph. - Graph is appropriately labeled. - Data points and error bars are correctly plotted. - 30
(c)	Accept one of the following: - As the temperature increases, the rate of ATP synthesis also increases. - There is a positive relationship (between temperature and ATP synthesis). - Temperature and ATP synthesis are directly correlated. 1,650 [16.5 nmol/min/mg × 10 mg × 10 min]

(d)	 **Predict** the effects of using oligomycin on the proton gradient across the inner mitochondrial membrane. Accept one of the following: - (The proton gradient) will increase/become steeper (and may eventually plateau). - The difference in the concentration of protons/pH (across the inner mitochondrial membrane) will increase. - There will be an increase in the concentration of protons/a decrease in pH in the intermembrane space relative to that found within the mitochondrial matrix. **Justify** your prediction. Accept one of the following: - (Without protons being able to flow back into the matrix through ATP synthase), more protons will accumulate in the intermembrane space/between the two mitochondrial membranes. - (Without protons being able to flow back into the matrix through ATP synthase), there will be a lower pH in the intermembrane space/between the two mitochondrial membranes. - Protons will not be able to flow across the membrane (through ATP synthase), but the electron transport chain will still pump protons into the intermembrane space.
Scoring Statistics	
Mean: 3.65	Standard Deviation: 2.15

2023 #4	
Course Content	Practice and Skill
3.4: Photosynthesis - 3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.
Part	Scoring Guidelines
(a)	 **Describe** the role of chlorophyll in the photosystems of plant cells. Accept one of the following: - Chlorophyll captures/absorbs light (energy). - Chlorophyll receives electrons (from water)/receives electrons (from an electron transport chain)/transfers electrons (to an electron transport chain).
(b)	 Based on Figure 1, **explain** why an increase in the ratio of NADPH to $NADP^+$ will cause an increase in the flow of electrons through the cyclic pathway. - There is less/no $NADP^+$ to accept the electrons, so the electrons pass (instead) to the cyclic pathway/from ferredoxin to the cytochrome complex.

(c)	Using rice plants, scientists examined the effect of a mutation that results in the loss of the protein CRR6. CRR6 is a part of the photosystem I complex, and its absence reduces the activity of photosystem I. **Predict** the effect of the mutation on the rate of biomass (dry weight) accumulation. • The rate (of biomass accumulation)/Biomass/It will be lower (in comparison with plants without the mutation).
(d)	**Justify** your prediction in part (c). • There will be insufficient ATP/NADPH produced for the synthesis of carbohydrates/the Calvin cycle.

Scoring Statistics	
Mean: 1.17	Standard Deviation: 1.00

2022 #3

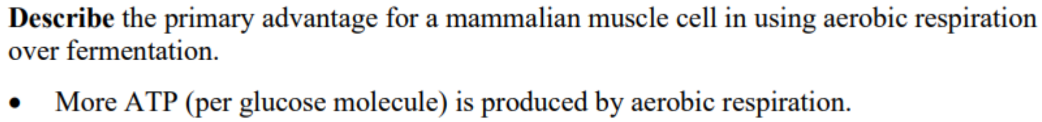
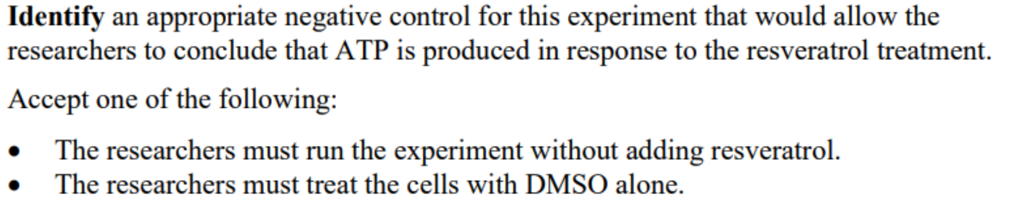
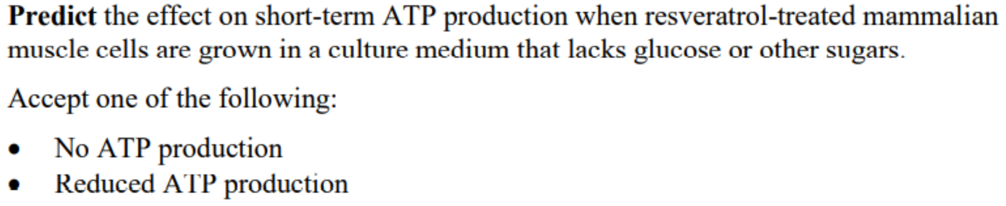
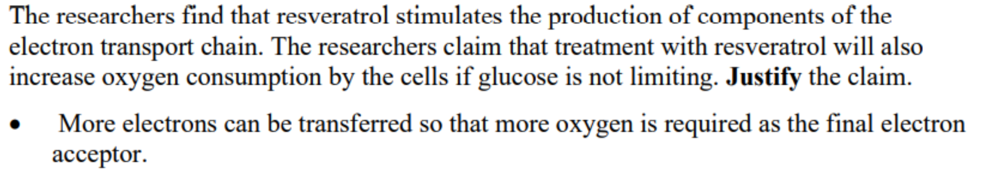
Course Content	Practice and Skill
3.1: Enzymes • 3.1.A: Explain how enzymes affect the rate of biological reactions. 3.2: Environmental Impacts on Enzyme Function • 3.2.B: Explain how the cellular environment affects enzyme activity.	1.A: Describe biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines
(a)	**Describe** a characteristic of the luciferase enzyme that allows it to catalyze the reaction. Accept one of the following: • It has an active site/a shape that can bind with the substrate(s)/brings reactants together. • It has a charge that is compatible with the substrate(s).
(b)	**Identify** the dependent variable in the experiment. • The amount of light emitted
(c)	**State** the null hypothesis for the experiment. • Temperature has no effect on the amount of light emitted.
(d)	A student claims that, as temperature increases, there will be an increase in the amount of light given off by the reaction in the first three seconds. **Support** the student's claim. Accept one of the following: • Higher temperature increases the frequency of collisions/interactions between molecules, resulting in an increase in reaction rate. • The higher temperature results in a change to the active site that enhances substrate binding.

Scoring Statistics	
Mean: 1.43	Standard Deviation: 1.12

2021 #3

Course Content	Practice and Skill
3.5: Cellular Respiration • 3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.	1.A: Describe biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

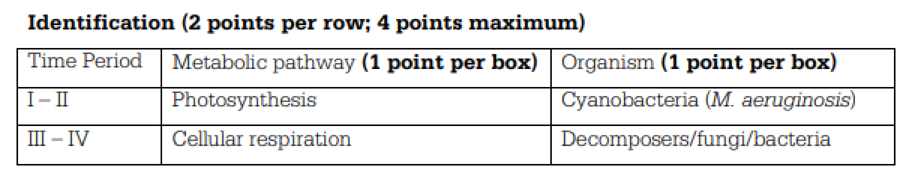
Part	Scoring Guidelines
(a)	 **Describe** the primary advantage for a mammalian muscle cell in using aerobic respiration over fermentation. • More ATP (per glucose molecule) is produced by aerobic respiration.
(b)	 **Identify** an appropriate negative control for this experiment that would allow the researchers to conclude that ATP is produced in response to the resveratrol treatment. Accept one of the following: • The researchers must run the experiment without adding resveratrol. • The researchers must treat the cells with DMSO alone.
(c)	 **Predict** the effect on short-term ATP production when resveratrol-treated mammalian muscle cells are grown in a culture medium that lacks glucose or other sugars. Accept one of the following: • No ATP production • Reduced ATP production
(d)	 The researchers find that resveratrol stimulates the production of components of the electron transport chain. The researchers claim that treatment with resveratrol will also increase oxygen consumption by the cells if glucose is not limiting. **Justify** the claim. • More electrons can be transferred so that more oxygen is required as the final electron acceptor.

Scoring Statistics	
Mean: 1.54	Standard Deviation: 1.10

2017 #5

Course Content	Practice and Skill
3.4: Photosynthesis • 3.4.A: Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy. 3.5: Cellular Respiration • 3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules.	2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 4.B: Describe data from a table or graph

Part	Scoring Guidelines



Identification (2 points per row; 4 points maximum)

Time Period	Metabolic pathway **(1 point per box)**	Organism **(1 point per box)**
I – II	Photosynthesis	Cyanobacteria (*M. aeruginosis*)
III – IV	Cellular respiration	Decomposers/fungi/bacteria

Scoring Statistics

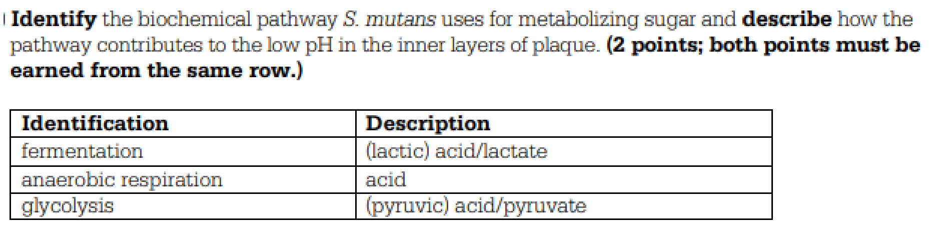
Mean: 1.81	Standard Deviation: 1.51

2017 #7

Course Content	Practice and Skill
3.5: Cellular Respiration • 3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions.	1.C: Explain biological concepts and processes in applied contexts. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part — **Scoring Guidelines**

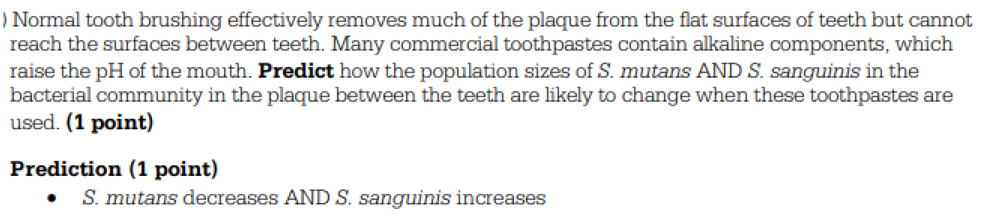
(a)



Identify the biochemical pathway *S. mutans* uses for metabolizing sugar and **describe** how the pathway contributes to the low pH in the inner layers of plaque. **(2 points; both points must be earned from the same row.)**

Identification	Description
fermentation	(lactic) acid/lactate
anaerobic respiration	acid
glycolysis	(pyruvic) acid/pyruvate

(b)



Normal tooth brushing effectively removes much of the plaque from the flat surfaces of teeth but cannot reach the surfaces between teeth. Many commercial toothpastes contain alkaline components, which raise the pH of the mouth. **Predict** how the population sizes of *S. mutans* AND *S. sanguinis* in the bacterial community in the plaque between the teeth are likely to change when these toothpastes are used. **(1 point)**

Prediction (1 point)

- *S. mutans* decreases AND *S. sanguinis* increases

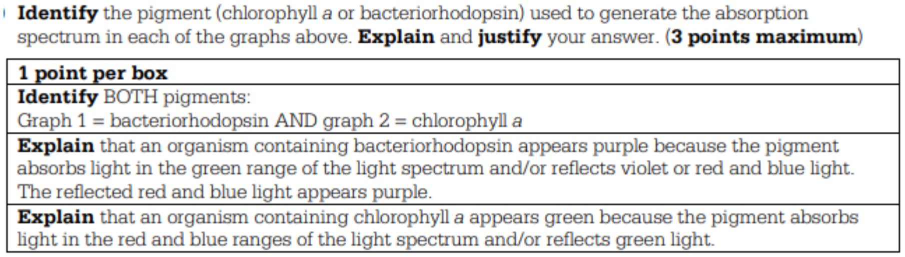
Scoring Statistics

Mean: 0.76	Standard Deviation: 0.99

2013 #2

Part — **Scoring Guidelines**

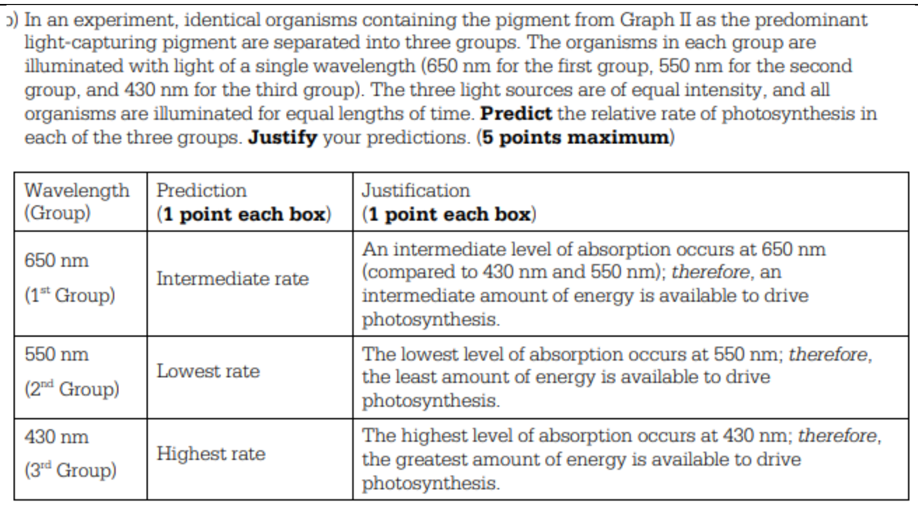
(a)



Identify the pigment (chlorophyll *a* or bacteriorhodopsin) used to generate the absorption spectrum in each of the graphs above. **Explain** and **justify** your answer. (**3 points maximum**)

1 point per box
Identify BOTH pigments: Graph 1 = bacteriorhodopsin AND graph 2 = chlorophyll *a*
Explain that an organism containing bacteriorhodopsin appears purple because the pigment absorbs light in the green range of the light spectrum and/or reflects violet or red and blue light. The reflected red and blue light appears purple.
Explain that an organism containing chlorophyll *a* appears green because the pigment absorbs light in the red and blue ranges of the light spectrum and/or reflects green light.

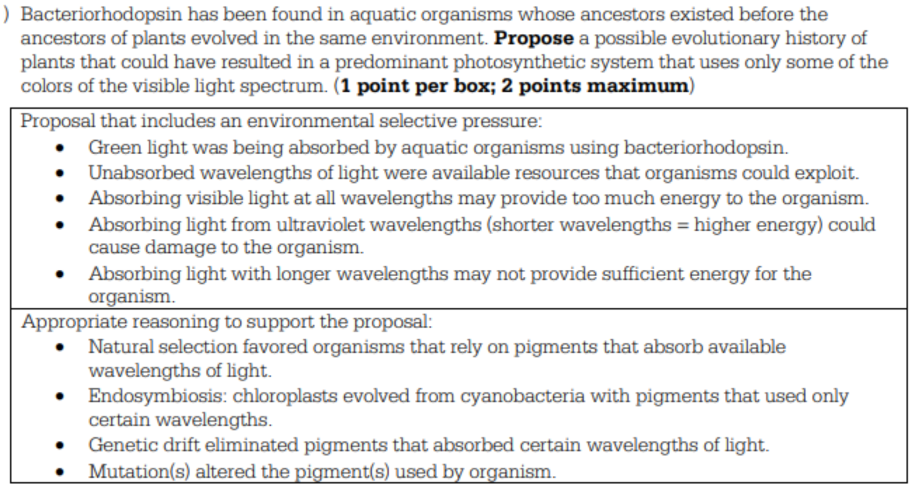
(b)



) In an experiment, identical organisms containing the pigment from Graph II as the predominant light-capturing pigment are separated into three groups. The organisms in each group are illuminated with light of a single wavelength (650 nm for the first group, 550 nm for the second group, and 430 nm for the third group). The three light sources are of equal intensity, and all organisms are illuminated for equal lengths of time. **Predict** the relative rate of photosynthesis in each of the three groups. **Justify** your predictions. (**5 points maximum**)

Wavelength (Group)	Prediction (**1 point each box**)	Justification (**1 point each box**)
650 nm (1st Group)	Intermediate rate	An intermediate level of absorption occurs at 650 nm (compared to 430 nm and 550 nm); *therefore*, an intermediate amount of energy is available to drive photosynthesis.
550 nm (2nd Group)	Lowest rate	The lowest level of absorption occurs at 550 nm; *therefore*, the least amount of energy is available to drive photosynthesis.
430 nm (3rd Group)	Highest rate	The highest level of absorption occurs at 430 nm; *therefore*, the greatest amount of energy is available to drive photosynthesis.

(c)



) Bacteriorhodopsin has been found in aquatic organisms whose ancestors existed before the ancestors of plants evolved in the same environment. **Propose** a possible evolutionary history of plants that could have resulted in a predominant photosynthetic system that uses only some of the colors of the visible light spectrum. (**1 point per box; 2 points maximum**)

Proposal that includes an environmental selective pressure:

- Green light was being absorbed by aquatic organisms using bacteriorhodopsin.
- Unabsorbed wavelengths of light were available resources that organisms could exploit.
- Absorbing visible light at all wavelengths may provide too much energy to the organism.
- Absorbing light from ultraviolet wavelengths (shorter wavelengths = higher energy) could cause damage to the organism.
- Absorbing light with longer wavelengths may not provide sufficient energy for the organism.

Appropriate reasoning to support the proposal:

- Natural selection favored organisms that rely on pigments that absorb available wavelengths of light.
- Endosymbiosis: chloroplasts evolved from cyanobacteria with pigments that used only certain wavelengths.
- Genetic drift eliminated pigments that absorbed certain wavelengths of light.
- Mutation(s) altered the pigment(s) used by organism.

Scoring Statistics	
Mean: 3.70	Standard Deviation: 2.72

Unit 4: Cell Communication and Cell Cycle

Topic	Learning Objective(s)
4.1 Cell Communication	**4.1.A:** Describe the ways that cells can communicate with one another. **4.1.B:** Explain how cells communicate with one another over short and long distances.
4.2 Introduction to Signal Transduction	**4.2.A:** Describe the components of a signal transduction pathway **4.2.B:** Describe the role of components of a signal transduction pathway in producing a cellular response.
4.3 Signal Transduction Pathways	**4.3.A:** Describe the different types of cellular responses elicited by a signal transduction pathway **4.3.B:** Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway
4.4 Feedback	**4.4.A:** Explain how positive and negative feedback helps maintain homeostasis.
4.5 Cell Cycle	**4.5.A:** Describe the events that occur in the cell cycle. **4.5.B:** Explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.
4.6 Regulation of Cell Cycle	**4.6.A:** Describe the role of checkpoints in regulating the cell cycle. **4.6.B:** Describe the effects of disruptions to the cell cycle on the cell or organism.

Additional Resources

Unit 4 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

Topic 4.1: Cell Communication

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.1.A: Describe the ways that cells can communicate with one another.	
4.1.A.1: Cells communicate with one another through direct contact with other cells or from a distance via chemical signaling.	☐ I can describe ways that cells communicate by direct cell-to-cell contact ☐ I can describe ways that cells communicate from a distance by chemical signaling

1. Identify a message communicated by direct cell-to-cell contact.
    a. What occurs during this process?
2. Identify a message communicated by chemical signaling.
    a. What occurs during this process?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.1.B: Explain how cells communicate with one another over short and long distances.	
4.1.B.1: Cells communicate over short distances by using local regulators that target cells in the vicinity of the signal-emitting cell.	☐ I can describe ways cells communicate with one another over short distances ☐ I can describe local regulators ☐ I can describe ways cells release signals ☐ I can describe ways cells receive signals ☐ I can determine which cells will respond to a specific signaling molecule

3. How do cells communication over a short distance?
    a. Identify two examples.
4. What is the process that results in the release of a chemical signal from a cell?
    a. Where are the chemical signals synthesized?
    b. Where are the chemical signals processed?
5. Reception
    a. What occurs during reception?
    b. Where is the receptor for a steroid hormone?
    c. Where is the receptor for a protein hormone?
    d. Why would the receptor be in different locations?
6. True or False: Only specific cells will respond to specific chemical signals because they have a receptor for the chemical signal.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.1.B: Explain how cells communicate with one another over short and long distances.	
4.1.B.2: Signals released by one cell type can travel long distances to target cells of another type.	☐ I can describe ways cells communicate with one another over long distances ☐ I can describe ways signals travel long distances

7. How do cells communication over a long distance?
    a. Identify one example.
8. How do signals travel in the blood stream?
9. What determines which cells respond to long distance signaling molecules?

Topic 4.2: Introduction to Signal Transduction

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">4.2.A: Describe the components of a signal transduction pathway</td></tr>
<tr><td>4.2.A.1: Signal transduction pathways link signal receptions with cellular responses.</td><td>☐ I can describe the components of a signal transduction pathway
☐ I can describe the process of reception
☐ I can describe the process of transduction
☐ I can describe the process of response</td></tr>
</table>

1. What are the components of a signal transduction pathway?
2. What occurs during the process of reception?
3. What occurs during the process of transduction?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">4.2.A: Describe the components of a signal transduction pathway</td></tr>
<tr><td>4.2.A.2: Many signal transduction pathways include protein modifications and involve phosphorylation cascades.</td><td>☐ I can describe phosphorylation cascades
☐ I can describe protein modification in transduction</td></tr>
</table>

4. What is a phosphorylation cascade?
5. What is the function of a kinase?
6. What is the function of a phosphatase?
7. How are proteins modified during the process of transduction?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.</td></tr>
<tr><td>4.2.B.1: Signaling begins with the recognition of a chemical messenger—a ligand—by a receptor protein in a target cell.
i. The ligand-binding domain of a receptor recognizes a specific chemical messenger, which can be a peptide (protein) or a small molecule.
ii. G-protein-coupled receptors are an example of a receptor protein in eukaryotes.
iii. Receptors may be located on the surface of a target cell or in the cytoplasm or nucleus of the target cell.</td><td>☐ I can describe the steps involved in reception
☐ I can describe ligands
☐ I can describe receptors
☐ I can draw connections between the location of receptors and the ligand's polarity</td></tr>
</table>

8. What are ligands?
9. What is the role of the ligand in the signal transduction pathway?
10. What is the role of the receptor in the signal transduction pathway?
11. Where does the ligand bind on the receptor?
12. What occurs with a G-protein coupled receptor after binding to a ligand?
13. What occurs with a tyrosine kinase receptor after binding to a ligand?
14. What occurs with an ion channel receptor after binding to a ligand?
15. How are signals amplified after reception?
16. What occurs when the ligand binds to the receptor that initiated transduction?
17. Where are receptors located?
    a. How does the receptor located correlate with the polarity of the ligand?
18. Why would a different cell respond differently to the same chemical signal?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.	
4.2.B.2: Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell. Responses could include cell growth, secretion of molecules, or gene expression. i. After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal. ii. Enzymes and second messengers such as cyclic AMP (cAMP) relay and amplify the intracellular signal. iii. Hormones are an example of a signaling messenger that can travel long distances in the bloodstream. **iv.** The binding of ligands to ligand-gated channels can cause the channel to open or close.	☐ I can describe the steps involved in transduction ☐ I can describe ways that signals are amplified in the signal transduction pathway ☐ I can describe second messengers' functions ☐ I can describe ways that secondary messengers amplify the signal ☐ I can describe examples of long-distance signaling molecules ☐ I can describe potential responses to signaling molecules ☐ I can describe ways that ligands binding to ligand-gated channels can cause cellular response

19. What are the steps involved in transduction?
20. How are signals amplified after reception?
21. What is a second messenger?
    a. Identify two examples.
    b. What is the function of a second messenger?
    c. How does a secondary messenger amplify the signal?

22. Identify TWO examples of long-distance signaling molecules.
    a. Provide an example of the signal transduction pathway for one of your examples.
    b. Provide a diagram of the signal transduction pathway for the other one of your examples.
23. Identify three possible cellular responses.
24. Describe the response when a ligand binds to a channel.
    a. How does this cause a cellular response?

Topic 4.3: Signal Transduction Pathway

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.3.A: Describe the different types of cellular responses elicited by a signal transduction pathway	
4.3.A.1: Signal transduction may result in changes in gene expressions and cell function, which may alter phenotype or result in programmed cell death (apoptosis).	☐ I can describe different types of cell responses due to a signal transduction pathway ☐ I can describe ways that a signal can change gene expression ☐ I can describe ways that a signal can change phenotype ☐ I can describe apoptosis

1. Describe how a signal can change gene expression.
    a. Provide a diagram that demonstrates this change in gene expression.
2. What is a transcription factor?
3. How does a transcription factor change gene expression?
4. How can a signal change the phenotype of an organism?
5. What is apoptosis?
6. Why would a cell undergo apoptosis?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway	
4.3.B.1: Changes in signal transduction pathways can alter cellular responses. Mutations in any domain of the receptor protein or in any component of the signaling pathway may affect the downstream components by altering the subsequent transduction of the signal.	☐ I can explain ways a change in structure of a signaling molecule affects the activity of the pathway ☐ I can describe the effect of a mutation in the receptor protein ☐ I can describe the effect of a mutation in the transduction protein

7. What would happen if there was a mutation in the receptor protein?
    a. How would this affect the response of the cell?
8. What would happen if there was a mutation in a transduction protein?
    a. How would this affect the response of the cell?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway	
4.3.B.2: Chemicals that interact with any component of the signaling pathway may activate or inhibit the pathway.	☐ I can explain ways that chemicals may activate a signal transduction pathway ☐ I can explain ways that chemicals may inhibit a signal transduction pathway

9. How can a chemical interfere with the signaling pathway?
10. Identify one example of a chemical that activates a signaling pathway.
11. Identify one example of a chemical that inhibits a signaling pathway.

Topic 4.4: Feedback

<table>
<tr><td colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</td></tr>
<tr><td colspan="2">4.4.A: Explain how positive and negative feedback helps maintain homeostasis.</td></tr>
<tr><td>4.4.A.1: Organisms use feedback mechanisms to maintain their internal environments in response to internal and external changes.
i. Negative feedback mechanisms maintain homeostasis by reducing the initial stimulus to regulate physiological processes. If a system is perturbed or disrupted, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular, cellular, and organismal levels.
ii. Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved further away from the initial set point. Amplification occurs when the stimulus is further intensified, which, in turn, initiates an additional response that produces system change.</td><td>☐ I can describe positive feedback mechanisms.
☐ I can describe negative feedback mechanisms.
☐ I can describe ways organisms use feedback mechanisms to maintain homeostasis.
☐ I can describe ways organisms respond to internal and external environmental changes.
☐ I can explain ways negative feedback helps to maintain homeostasis.
☐ I can explain ways negative feedback returns a system back to target set point after disruptions.
☐ I can explain ways positive feedback affects homeostasis.
☐ I can explain ways positive feedback amplifies the response.</td></tr>
</table>

1. What is positive feedback?
    a. Identify two examples of positive feedback loops.
2. What is negative feedback?
    a. Identify two examples of negative feedback loops.
3. Using an internal change, describe how an organism responds using feedback loops.
4. Using an external change, describe how an organism responds using feedback loops.
5. Using an example, explain how negative feedback can be used to maintain homeostasis?
6. How does a cell use negative feedback to return to a target set point after a disturbance?
7. Using an example, explain how positive feedback can be used to maintain homeostasis?
8. How does positive feedback amplify the response?
    a. Identify one example.

AP Biology Exam Review

Topic 4.5: Cell Cycle

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">**4.5.A:** Describe the events that occur in the cell cycle.</td></tr>
<tr><td>**4.5.A.1:** The cell cycle is a highly regulated series of events that controls the growth and reproduction of eukaryotic cells.
i. The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis.
ii. G1 phase: The cell is metabolically active, duplicating organelles and cytosolic components.
iii. S phase: DNA is in the form of chromatin and replicates to form two sister chromatids connected at a centromere.
iv. G2 phase: Protein synthesis occurs, ATP is produced in large quantities, and centrosomes replicate.
v. A cell can enter a stage (G0) in which it no longer divides, but it can reenter the cell cycle in response to appropriate cues.
vi. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle</td><td>☐ I can describe the events of the cell cycle.
☐ I can describe the phases of interphase.
☐ I can describe G1 phase.
☐ I can describe S phase.
☐ I can describe G2 phase.
☐ I can describe G0 phase.
☐ I can describe how a cell exits the cell cycle and enters G0 then re-enters the cell cycle.</td></tr>
</table>

1. What are the THREE phases of the cell cycle?
    a. What occurs in each of these three phases?
2. What are the THREE phases of interphase?
    a. What occurs in each of these phases?
3. What is G_0?
4. What occurs to re-enter the cell cycle from G_0?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">**4.5.B:** Explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.</td></tr>
<tr><td>**4.5.B.1:** Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells in eukaryotes.</td><td>☐ I can explain how mitosis results in the transmission of chromosomes from one generation of cells to the next.
☐ I can describe mitosis.</td></tr>
</table>

i. Mitosis plays a role in growth, tissue repair, and asexual reproduction. ii. Mitosis occurs in sequential steps (prophase, metaphase, anaphase, telophase) and alternates with interphase in the cell cycle. iii. Prophase: Sister chromatids condense, mitotic spindle begins to form, and centrosomes move to opposite poles of the cell. iv. Metaphase: Spindle fibers align chromosomes along the equator of the cell. v. Anaphase: Paired sister chromatids separate as spindle fibers pull chromatids toward poles. vi. Telophase: Mitotic spindle breaks down, a new nuclear envelope develops, and then the cytoplasm divides. vii. Cytokinesis: A cleavage furrow forms in animal cells or a cell plate forms in plant cells, resulting in two new daughter cells.	☐ I can describe the function of mitosis. ☐ I can compare a parent and daughter cell in mitosis. ☐ I can describe the phases of mitosis. ☐ I can describe prophase. ☐ I can describe metaphase. ☐ I can describe anaphase. ☐ I can describe telophase. ☐ I can describe cytokinesis. ☐ I can explain ways that mitosis ensures equal transfer of chromosomes ☐ I can explain ways that mitosis results in identical genetic information transfer ☐ I can explain phases of mitosis that result in equal transfer of chromosomes

5. What is mitosis?
    a. How does the parent cell compare to the daughter cells?
6. Describe the function of mitosis.
7. Identify three roles of mitosis.
8. What are the FOUR phases of mitosis?
    a. What occurs in each of these phases?
9. What occurs during cytokinesis?
10. How is cytokinesis different in a plant versus an animal?
11. How does the cell undergo cytokinesis?
12. What phase(s) in mitosis ensures equal transfer of chromosomes?
    a. Describe how this/these phase(s) ensure(s) the equal transfer of chromosomes.
13. What phase(s) in mitosis ensures a result of identical genetic information transfer.
    a. Describe how this/these phase(s) ensure(s) a result of identical genetic information transfer.

Topic 4.6: Regulation of Cell Cycle

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">4.6.A: Describe the role of checkpoints in regulating the cell cycle.</td></tr>
<tr><td>4.6.A.1: A number of internal controls or checkpoints regulate progression through the cell cycle.</td><td>☐ I can describe the roles of checkpoints in regulating the cell cycle
☐ I can describe the roles of the G1 checkpoint.
☐ I can describe the role of the G2 checkpoint.
☐ I can describe the role of the M checkpoint.
☐ I can describe the molecular components that allow for passage of checkpoints.
☐ I can describe internal controls that allow for passage of checkpoints.</td></tr>
</table>

1. What occurs at the G_1 checkpoint?
2. What occurs at the G_2 checkpoint?
    a. What happens if the cell prematurely bypasses this checkpoint?
3. What occurs at the M checkpoint?
    a. What happens if the cell prematurely bypasses this checkpoint?
4. What process allows for the passage of the M checkpoint?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">4.6.A: Describe the role of checkpoints in regulating the cell cycle.</td></tr>
<tr><td>4.6.A.2: Interactions between cyclins and cyclin-dependent kinases control the cell cycle.
⌧ Exclusion Statement:
Knowledge of specific cyclin-CdK pairs or growth factors is beyond the scope of the AP Exam.</td><td>☐ I can describe the interaction between cyclin and cyclin dependent kinase.</td></tr>
</table>

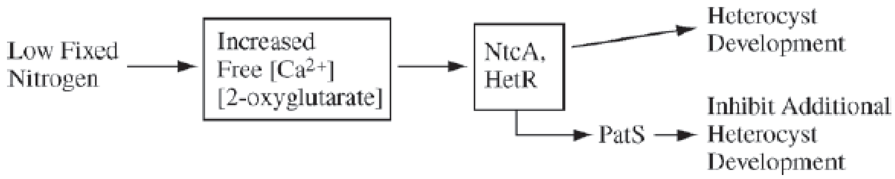
5. What are cyclins? What are CdKs?
    a. How do these two interact to allow passage of the G_2 checkpoint?
6. What is the function of kinase?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
4.6.B: Describe the effects of disruptions to the cell cycle on the cell or organism.	
4.6.B.1: Disruptions to the cell cycle may result in cancer or apoptosis (programmed cell death).	☐ I can describe the effects of disruptions on the cell cycle on the cell. ☐ I can describe the effects of disruptions on the cell cycle on the organism. ☐ I can describe the effects of cancer on the cell cycle ☐ I can describe the causes of apoptosis.

7. Identify ONE disruption on the cell cycle.
    a. Describe the effect of this disruption on the cell cycle
8. Identify three causes of cancer.
    a. How does each affect the cell cycle?
9. What is an oncogene?
10. What is a proto-oncogene?
11. How do the proto-oncogenes cause cancer?
12. What is a tumor suppressor gene?
13. How do the tumor-suppressor genes cause cancer?
14. What causes apoptosis?

Multiple Choice Practice

1. Anabaena is a simple multicellular photosynthetic cyanobacterium. In the absence of fixed nitrogen, certain newly developing cells along a filament express genes that code for nitrogen-fixing enzymes and become non-photosynthetic heterocysts. The specialization is advantageous because some nitrogen-fixing enzymes function best in the absence of oxygen. Heterocysts do not carry out photosynthesis but instead provide adjacent cells with fixed nitrogen, in exchange receiving fixed carbon and reduced energy carriers.

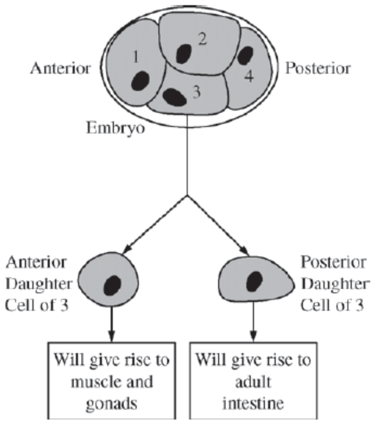

Low Fixed Nitrogen
Increased Free [Ca2+] [2-oxyglutarate]
NtcA, HetR
Heterocyst Development
PatS
Inhibit Additional Heterocyst Development

As shown in the diagram above, when there is low fixed nitrogen in the environment, an increase in the concentration of free calcium ions and 2-oxyglutarate stimulates the expression of genes that produce two transcription factors (NtcA and HetR) that promote the expression of genes responsible for heterocyst development. HetR also causes production of a signal, PatS, that prevents adjacent cells from developing as heterocysts.

Based on your understanding of the ways in which signal transmission mediates cell function, which of the following predictions is most consistent with the information given above?

   a. In an environment with low fixed nitrogen, treating the Anabaena cells with a calcium-binding compound should prevent heterocyst differentiation.
   b. A strain that overexpresses the patS gene should develop many more heterocysts in a low fixed nitrogen environment.
   c. In an environment with abundant fixed nitrogen, free calcium levels should be high in all cells so that no heterocysts develop.
   d. In environments with abundant fixed nitrogen, loss of the hetR gene should induce heterocyst development.

2. The diagram below shows a developing worm embryo at the four-cell stage. Experiments have shown that when cell 3 divides, the anterior daughter cell gives rise to muscle and gonads and the posterior daughter cell gives rise to the intestine. However, if the cells of the embryo are separated from one another early during the four-cell stage, no intestine will form. Other experiments have shown that if cell 3 and cell 4 are recombined after the initial separation, the posterior daughter cell of cell 3 will once again give rise to normal intestine.

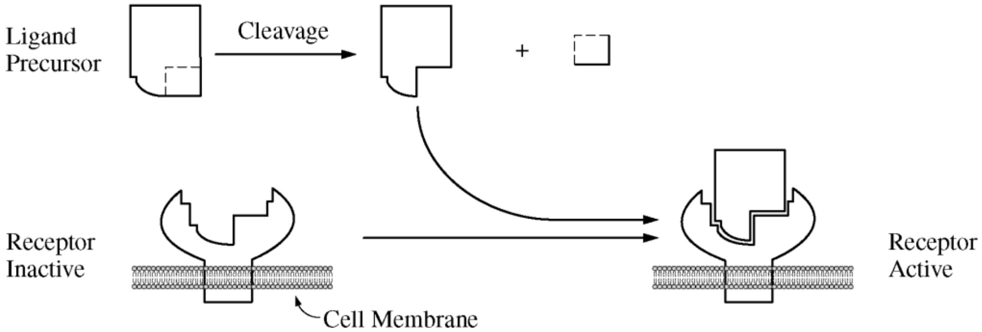

Anterior
Posterior
1
2
3
4
Embryo
Anterior Daughter Cell of 3
Posterior Daughter Cell of 3
Will give rise to muscle and gonads
Will give rise to adult intestine

Which of the following is the most plausible explanation for these findings?

   a. A cell surface protein on cell 4 signals cell 3 to induce formation of the worm's intestine.
   b. The plasma membrane of cell 4 interacts with the plasma membrane of the posterior portion of cell 3, causing invaginations that become microvilli.
   c. Cell 3 passes an electrical signal to cell 4, which induces differentiation in cell 4.
   d. Cell 4 transfers genetic material to cell 3, which directs the development of intestinal cells.

3. The vertebrate forelimb initially develops in the embryo as a solid mass of tissue. As development progresses, the solid mass near the end of the forelimb is remodeled into individual digits. Which of the following best explains the role of apoptosis in remodeling of the forelimb?
    a. Apoptosis replaces old cells with new ones that are less likely to contain mutations.
    b. Apoptosis involves the regulated activation of proteins in specific cells of the developing forelimb that leads to the death of those cells.
    c. Apoptosis involves the destruction of extra cells in the developing forelimb, which provides nutrients for phagocytic cells.
    d. Apoptosis in the developing forelimb triggers the differentiation of cells whose fate was not already determined.

4. The figure below shows a model of a ligand precursor being cleaved to produce an active ligand that binds to a specific receptor. Which of the following is most likely to reduce the binding of the active ligand to its receptor?



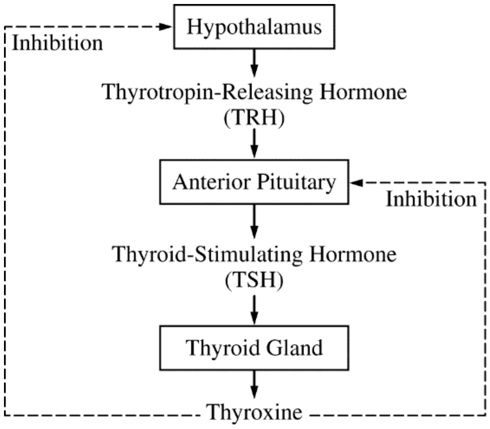
    a. A change in the cytoskeletal attachment of transmembrane proteins
    b. The presence of a large amount of the precursor form of the ligand
    c. An increase in the ratio of the number of unsaturated to the number of saturated fatty acid tails of the membrane lipids
    d. A mutation in the receptor gene that causes a substitution of a charged amino acid for a nonpolar amino acid in the ligand binding site of the receptor

5. Insulin is a protein hormone that is secreted in response to elevated blood glucose levels. When insulin binds to its receptors on liver cells, the activated receptors stimulate phosphorylation cascades that cause the translocation of glucose transporters to the plasma membrane.

    Based on the information provided, which of the following best describes the role of insulin in this liver cell signal transduction pathway?
    a. It acts as a ligand.
    b. It acts as a receptor.
    c. It acts as a secondary messenger.
    d. It acts as a protein kinase.

6. The endocrine system incorporates feedback mechanisms that maintain homeostasis. Which of the following demonstrates negative feedback by the endocrine system?
    a. During labor, the fetus exerts pressure on the uterine wall, inducing the production of oxytocin, which stimulates uterine wall contraction. The contractions cause the fetus to further push on the wall, increasing the production of oxytocin.
    b. After a meal, blood glucose levels become elevated, stimulating beta cells of the pancreas to release insulin into the blood. Excess glucose is then converted to glycogen in the liver, reducing blood glucose levels.
    c. At high elevation, atmospheric oxygen is more scarce. In response to signals that oxygen is low, the brain decreases an individual's rate of respiration to compensate for the difference.
    d. A transcription factor binds to the regulatory region of a gene, blocking the binding of another transcription factor required for expression.

7. The diagram below illustrates feedback control as exerted by the hormone thyroxine. Following surgical removal of the thyroid gland, the level of TSH in the blood will increase. Which of the following best explains this increase?



    a. Residual blood thyroxine, from prior to thyroid gland removal, will bind to cells in the anterior pituitary, signaling more TSH secretion.
    b. Thyroxine will remain bound to thyroxine receptors on various body cells, and these body cells will secrete additional hormones that stimulate the anterior pituitary to secrete TSH.
    c. Thyroxine that was stored in the anterior pituitary prior to thyroid gland removal will signal more TSH secretion.
    d. A decrease in thyroxine levels means a loss of inhibition to the hypothalamus and anterior pituitary, leading to increased TSH secretion.

8. Antidiuretic hormone (ADH) is important in maintaining homeostasis in mammals. ADH is released from the hypothalamus in response to high tissue osmolarity. In response to ADH, the collecting duct and distal tubule in the kidney become more permeable to water, which increases water reabsorption into the capillaries. The amount of hormone released is controlled by a negative feedback loop. Based on the model presented, which of the following statements expresses the proper relationship between osmolarity, ADH release, and urine production?
    a. As tissue osmolarity rises, more ADH is released, causing less water to be excreted as urine.
    b. As tissue osmolarity rises, less ADH is released, causing less water to be excreted as urine.
    c. As tissue osmolarity rises, more ADH is released, causing more water to be excreted as urine.
    d. As tissue osmolarity rises, less ADH is released, causing more water to be excreted as urine.

Use the following information to answer question 9:

Platelets are fragments of larger cells and normally circulate in the blood without adhering to blood vessel walls. When the wall of a blood vessel is damaged, collagen fibers in the wall are exposed to the interior of the blood vessel. The exposed fibers and chemicals released from the endothelial cells that line the blood vessel attract platelets, which start to form a plug and release other chemicals (Figure 1).

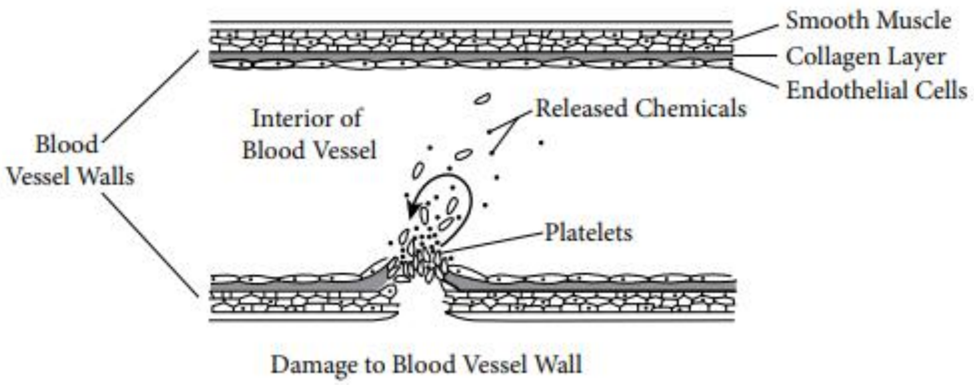


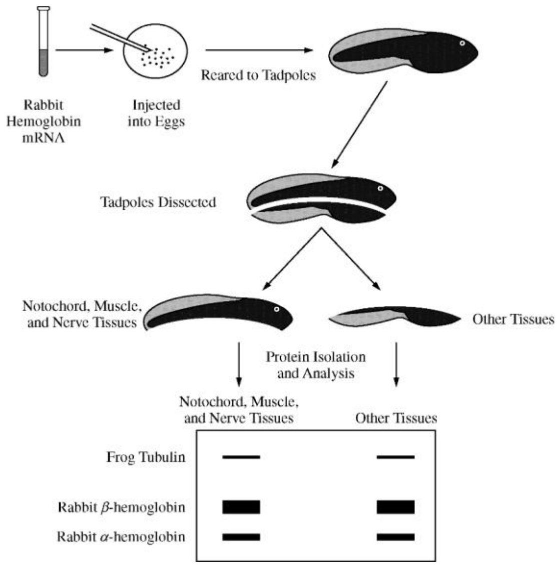
Figure 1. Formation of a platelet plug in a damaged blood vessel wall

9. Which of the following best explains the feedback mechanism illustrated in Figure 1?
    a. This is an example of positive feedback, because the few platelets that initially bind attract more platelets to the damaged area.
    b. This is an example of positive feedback, because it results from the interactions among collagen, endothelial cells, and platelets.
    c. This is an example of negative feedback, because a large clump of platelets can block the blood vessel and prevent blood flow through it.
    a. This is an example of negative feedback, because the accumulation of platelets returns the open blood vessel wall to a closed state.

Use the following information to answer question 10:

In a classic experiment from the 1970s investigating gene expression, a solution containing equal amounts of rabbit a-hemoglobin mRNA and b-hemoglobin mRNA, which encode subunits of a protein found in red blood cells, was injected into newly fertilized frog eggs. The injected mRNA was not degraded during the course of the experiment. Tadpoles that developed from the injected eggs were dissected into two fragments, one containing predominantly the notochord, muscle tissue, and nerve tissue and the other containing predominantly the other tissue types.

Equal amounts of total protein were analyzed after separation by electrophoresis to identify the relative amounts of the different proteins present in each sample. The thickness of the bands indicates the relative amounts of rabbit a-hemoglobin, rabbit b-hemoglobin, and frog tubulin (a cytoskeletal protein that is expressed at relatively constant levels in all tissues) present in each tadpole sample. The experimental protocol and results are summarized in the figure below.



10. Which of the following is the best justification for why the rabbit hemoglobin proteins were found throughout the tadpole?
    a. Rabbit mRNA is composed of nucleotides that are more stable than those in frog mRNA.
    b. Rabbit hemoglobin is synthesized more efficiently than frog hemoglobin in frog cells.
    c. After differentiation, the rabbit hemoglobin proteins move through the circulatory system of the tadpole to every cell.
    d. The mRNA injected into the newly fertilized frog eggs is distributed in the cytoplasm of every daughter cell during cell division.

11. If chemical signals in the cytoplasm control the progression of a cell to the M phase of the cell cycle, then fusion of a cell in G_1 with a cell in early M phase would most likely result in the
    a. replication of chromosomes only in the G_1 cell
    b. exiting of both cells from the cell cycle and into the G_0 phase
    c. condensation of chromatin in preparation of nuclear division in both cells
    d. transfer of organelles from the G_1 cell to the cell in the M phase

12. What are the three parts of signal transduction pathway?
    a. reception, transduction, response
    b. confirmation, transduction, transcription
    c. reception, amplification, transcription
    d. confirmation, amplification, response

13. Transduction step traditionally amplifies the signal, which of the following are NOT involved with transduction?
    a. secondary messengers
    b. protein modification
    c. phosphorylation cascade
    d. ligands

14. Which of the following is NOT a response by the cell from a signal transduction pathway?
    a. cell growth
    b. gene expression
    c. secretion of molecules
    d. all of the above are responses

15. Describe what occurs when the ligand binds to the receptor.
    a. confirmational change in shape of receptor
    b. phosphorylation of ligand
    c. ligand passes through the membrane
    d. receptor binds additional ligands

16. Describe the impact of a mutation in any domain of the protein components of the transduction signaling pathway.
    a. receptor unable to bind to ligand
    b. no changes in transduction due to initial signal transduction from ligand
    c. alters response of the cell
    d. amplification of signaling pathway to bind more ligands

17. Which feedback mechanism involves homeostasis of a particular condition by regulating physiological processes?
    a. Positive Feedback
    b. Negative Feedback

18. Which feedback mechanism involves amplifying responses and processes in biological organisms?
    a. Positive Feedback
    b. Negative Feedback

19. Which of the following is NOT a stage of the cell cycle?
    a. interphase
    b. cytokinesis
    c. mitosis
    d. apoptosis

20. Which of the following is the stage where the cell no longer divides?
    a. G_0
    b. G_1
    c. G_2
    d. S

21. Which of the following describes the order of the steps in mitosis?
    a. metaphase, telophase, anaphase, prophase
    b. prophase, metaphase, anaphase, telophase
    c. telophase, anaphase, metaphase, prophase
    d. prophase, anaphase, metaphase, telophase

22. Which of the following is NOT a role of mitosis?
    a. gametes
    b. tissue repair
    c. growth
    d. asexual reproduction

23. Which checkpoint is responsible for ensuring nondisjunction does not take place?
    a. G_1 checkpoint
    b. S checkpoint
    c. G_2 checkpoint
    d. M checkpoint

24. Describe the interaction between cyclin and CdK.
    a. cyclin interacts with CdK to initiate the mitotic phase
    b. cyclin is the precursor to CdK, when synthesized allow for mitosis proceed
    c. cyclin acts as an inhibitor to CdK to wait for all DNA to be synthesized
    d. cyclin binds to CdK to initiate DNA replication

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	A. In an environment with low fixed nitrogen, treating the Anabaena cells with a calcium-binding compound should prevent heterocyst differentiation.	4.1	2012 CED #38
2	A. A cell surface protein on cell 4 signals cell 3 to induce formation of the worm's intestine.	4.1	2012 CED #31
3	B. Apoptosis involves the regulated activation of proteins in specific cells of the developing forelimb that leads to the death of those cells.	4.3	2013 #16
4	D. A mutation in the receptor gene that causes a substitution of a charged amino acid for a nonpolar amino acid in the ligand binding site of the receptor	4.2	2013 #46
5	A. It acts as a ligand.	4.1	2020 CED #1
6	B. After a meal, blood glucose levels become elevated, stimulating beta cells of the pancre-as to release insulin into the blood. Excess glucose is then converted to glycogen in the liver, reducing blood glucose levels.	4.4	2012 CED #17
7	D. A decrease in thyroxine levels means a loss of inhibition to the hypothalamus and anterior pituitary, leading to increased TSH secretion.	4.4	2013 #39
8	A. As tissue osmolarity rises, more ADH is released, causing less water to be excreted as urine.	4.4	2013 #52
9	A. This is an example of positive feedback, because the few platelets that initially bind attract more platelets to the damaged area.	4.4	2020 CED #14
10	D. The mRNA injected into the newly fertilized frog eggs is distributed in the cytoplasm of every daughter cell during cell division.	4.5*	2013 #29
11	C. condensation of chromatin in preparation of nuclear division in both cells	4.5	2013 #35
12	A. reception, transduction, response	4.2	Self
13	D. ligands	4.2	Self
14	D. all of the above are responses	4.2	Self
15	A. confirmational change in shape of receptor	4.2	Self
16	C. alters response of the cell	4.3	Self
17	B. Negative Feedback	4.4	Self
18	A. Positive Feedback	4.4	Self
19	D. apoptosis	4.5	Self
20	A. G_0	4.5	Self
21	B. prophase, metaphase, anaphase, telophase	4.5	Self
22	A. gametes	4.5	Self
23	D. M checkpoint	4.6	Self
24	A. cyclin interacts with CdK to initiate the mitotic phase	4.6	Self

* no longer in AP Classroom so might be "out of scope"

Multiple Choice Explanations

Q		Explanation:
1	A	**As shown in the figure (and described in the prompt), if there is a low fixed nitrogen then there will be an increase in calcium which stimulates expression of genes that are responsible for heterocyst development. If there is a calcium-binding compound, the increase in calcium will be inhibited which inhibits the expression of the genes which inhibits heterocyst development.** **This option is correct because free calcium is needed for heterocyst formation. Binding the calcium will prevent cyst formation. This answer demonstrates that the student is able to refine representations to illustrate how interactions between external stimuli and gene expression result in specialization of cells. (CollegeBoard)**
	B	As shown in the figure, PatS inhibits additional heterocyst development. If the PatS is overexpressed, there will be additional inhibition of the heterocyst development. This option is incorrect because the patS gene inhibits heterocyst formation, so fewer would be produced. (CollegeBoard)
	C	As shown in the figure, the abundant fixed nitrogen does not cause the pathway. With an abundant fixed nitrogen level, there will not be an increased amount of calcium so there will also not be heterocyst development. This option is incorrect because in an environment with abundant fixed nitrogen, heterocysts are not an advantage to the organism in that the anaerobic nitrogen-fixing enzymes are not needed. (CollegeBoard)
	D	As shown in the figure, the abundant fixed nitrogen does not cause the pathway. There will not be HetR activated which will not activate the heterocyst development. This option is incorrect because loss of the hetR gene would prevent, not induce, heterocyst formation (CollegeBoard)
2	A	**There is a signaling molecule on the surface of cell 4. When cell 4 is not in contact with cell 3, it is unable to activate the pathway. When the cells are put back into contact, the signal transduction pathway leads to the formation of the intestines.** **This option is correct. The stem of the question indicates that cell 4 and cell 3 must be touching in order for cell 3 to induce formation of the intestine. This is the mechanism by which the correct timing of this developmental event occurs. (CollegeBoard)**
	B	Invagination is due to a signaling molecule that leads to the signal transduction pathway resulting in the invagination. The plasma membrane alone will not provide that signaling molecule. This option is incorrect because there is no indication that microvilli are formed. (CollegeBoard)
	C	Based on the prompt, cell 3 must be in contact with cell 4 in order for the posterior daughter cell to give rise to the intestines. This option is incorrect because there is no evidence of an electrical signal (CollegeBoard)
	D	All cells of an organism are genetically identical except the gametes. Cell 4 will not transfer genetic information that cell 3 didn't already have.

		This option is incorrect because there is no indication that genetic material is transferred from cell 4 to cell 3, resulting in the development of intestinal cells (CollegeBoard)
3	A	Apoptosis is programmed cell death. The cells are not going through this process to replace old cells.
	B	**Apoptosis is programmed cell death. This is due to a signaling transduction pathway leading to the cell digesting from the inside out. Initially, the forelimb is a solid mass of tissue, but after apoptosis there are spaces between the fingers to complete the formation of the forelimb.**
	C	Apoptosis is programmed cell death. Although the cell is broken down from the inside out then engulfed by macrophages, the goal is not to provide nutrients to the phagocytic cells.
	D	Apoptosis is programmed cell death. It does not cause differentiation.
4	A	The active site for the receptor would be on the extracellular region of the cell versus if there is a change in the cytoskeletal attachment of the protein. These are two different regions of the protein and thus the change has little effect on the protein.
	B	In order for the ligand to bind, it must be cleaved. If there is a large amount of the precursor. This means there could be a decrease in the binding to the active site.
	C	The number of unsaturated fatty acids to fatty acids will allow the membrane to maintain fluidity.
	D	**If there is a substitution with an amino acid that has a drastically different polarity, the protein will not fold correctly which leads to a difference in the binding of the ligand precursor and the enzyme's active site.**
5	A	**A ligand is a signaling molecule. This signaling molecule will bind to a receptor to initiate the signal transduction pathway. This is described in the prompt as "insulin binds to its receptors on the liver cells, the activated receptors stimulate phosphorylation cascades that cause the translocation of glucose transporters to the plasma membrane".**
	B	A receptor is the location where the ligand or signaling molecule binds. The prompt states that insulin binds to its receptor, so insulin can't be the receptor.
	C	The secondary messenger is found intracellular and is a component of the signal transduction pathway. After the primary messenger binds to the receptor then initiates the phosphorylation cascade, the secondary messenger acts as a small molecule intracellular to continue the transduction.
	D	Protein kinase is a component of the phosphorylation cascade. It has the role of phosphorylating a protein.
6	A	This describes positive feedback. The release of oxytocin causes contractions that increase the production of oxytocin. The product activates the pathway to lead to more production. This option is incorrect. The onset of labor is an example of a positive feedback mechanism, not a negative feedback mechanism. (CollegeBoard)
	B	**This describes negative feedback. The insulin is released in response to a high level of glucose binding to the liver to decrease the glucose level. This maintains homeostasis.** **This option is correct. The decrease of blood glucose levels as a result of insulin production is an example of how the endocrine system is involved in negative feedback, allowing organisms to maintain their internal environments. (CollegeBoard)**
	C	Oxygen levels are scarce. The answer choice describes that in response, there will be a decrease in respiration which cause less oxygen to be respirated. Organisms need oxygen which should cause an increase in respiration to increase amount of air consumed to increase the oxygen amount respirated. This option is incorrect. Respiration rates would increase, not decrease, in response to low oxygen levels. (CollegeBoard)

	D	Transcription binds to a regulatory region of a gene inhibiting the synthesis of the transcription factor. This is an example of negative feedback. The product will inhibit the process to produce more product. This option is incorrect. Transcription factors are not part of the endocrine system. (CollegeBoard)
7	A	If there is residual thyroxine and it binds to the anterior pituitary, the anterior pituitary is inhibited and will not release the TSH.
	B	This is not shown in the diagram. You need to use the diagram to answer the question.
	C	If thyroxine binds to the anterior pituitary, the thyroxine inhibits the anterior pituitary so TSH will not be released.
	D	**The thyroxine will inhibit the anterior pituitary from releasing TSH. In the absence of the thyroxine, there is no inhibitor so the anterior pituitary will continue releasing TSH leading to an increased production.**
8	A	**According to the prompt, ADH is released in response to high osmolarity. The ADH increases water reabsorption decreasing the amount of liquid in the filtrate (which becomes the urine). This aligns perfectly with this answer choice: As tissue osmolarity rises, more ADH is released (true) causing less water to be excreted (true).**
	B	As tissue osmolarity rises, less ADH is released (false). The prompt states the ADH is released in response to high osmolarity.
	C	As tissue osmolarity rises, more ADH is released (true) causing more water to be excreted (false). The prompt states ADH increases water absorption. If there is an increase in water reabsorption, there will be less water excreted.
	D	As tissue osmolarity rises, less ADH is released (false). The prompt states the ADH is released in response to high osmolarity.
9	A	**As seen in the figure, the platelets have a circular pathway. This shows that the platelets are simulating an increase in platelets to the area. This is an example of positive feedback as the product (platelets arriving at the damaged blood vessel) stimulates additional product (more platelets attracted to the area).**
	B	The released chemicals appear to come from another part of the vessel not the damaged site which does not show positive feedback.
	C	By blocking the blood vessel with the platelets decreases the blood loss, but this does not describe negative feedback. The blood does not inhibit a pathway nor does the platelet.
	D	By inhibiting the loss of blood, the open wall returns back to a closed wall. This is just a restoration versus a homeostatic balance.
10	A	The mRNA remains in ONE cell. True that the more stable, the more protein could be produced from it. The question is asking why the protein is found throughout the tadpole.
	B	The protein synthesis is in ONE cell. True that if the rabbit hemoglobin is synthesized more efficiently there would be more, but the question asks why the proteins are throughout the tadpole.
	C	If proteins are traveling in the bloodstream, the proteins would come in contact with all of the cells. Proteins are polar and would most likely not be distributed throughout the tadpole in this fashion.
	D	**Due to cell division, all of the cells would be identical. If the mRNA was injected into the eggs, the cytoplasm would be distributed to all of the resulting cells during the cleavage step (rapid cell division).**
11	A	Replication of chromosomes occurs during the S phase of interphase. This process takes place after G_1, but the signaling molecules in the cytoplasm would promote the cell through M phase.
	B	There are signaling molecules in the cytoplasm would promote the cell through the M phase prior to entering the G_0 phase.

	C	**During the M phase, the chromosomes are condensed, aligned on the metaphase plate, then separated to opposite poles. If the signals are in the cytoplasm, then when the G_1 cell fused with the M cell, the signaling molecules will bind in the G_1 cell promoting cell division.**
	D	There is no reason for the organelles to be transferred from one cell to another. This question is looking at the signaling molecules in division to determine how they would affect another cell.
12	A	**Reception is the binding of the signaling molecule (ligand) to the receptor. Transduction is the transfer of the signal (message) to the appropriate location for the next step. Response is the result of the pathway.**
	B	When the ligand binds to the receptor, the receptor undergoes a confirmational shape change but this step is called reception. Transcription is the process of reading DNA to synthesize an mRNA strand.
	C	During transduction, the signal will often be amplified and modified but this step is called transduction. Transcription is the process of reading DNA to synthesize an mRNA strand.
	D	When the ligand binds to the receptor, the receptor undergoes a confirmational shape change but this step is called reception. During transduction, the signal will often be amplified and modified but this step is called transduction.
13	A	Second messengers (such as cyclic AMP) are molecules that relay and amplify the intracellular signal (IST-3.D.2b).
	B	Many signal transduction pathways include protein modification and phosphorylation cascades (IST-3.C.2)
	C	Many signal transduction pathways include protein modification and phosphorylation cascades (IST-3.C.2)
	D	**Ligands are the signaling molecules. These will bind to the receptor for reception.**
14	A	Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression (IST-3.D.2)
	B	Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression (IST-3.D.2)
	C	Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression (IST-3.D.2)
	D	**Signaling cascades relay signals from receptors to cell targets, often amplifying the incoming signals, resulting in the appropriate responses by the cell, which could include cell growth, secretion of molecules, or gene expression (IST-3.D.2)**
15	A	**After the ligand binds, the intracellular domain of a receptor protein changes shape, initiating transduction of the signal. (IST-3.D.2a)**
	B	During transduction, the relay molecules are phosphorylated. The ligand does not get phosphorylated.
	C	Receptors do not act as transport proteins and cannot move the ligand across the membrane.
	D	This describes allosteric activator which binds to get the active site into the correct conformation for the other ligand.
16	A	Reception takes place before transduction, so a mutation in transduction would not affect the step the preceded.
	B	A mutation in the transduction pathway would lead to a change since the shape has changed to the protein which could change the function.

	C	**Changes in signal transduction pathways can alter cellular response— (a) Mutations in any domain of the receptor protein or in any component of the signaling pathway may affect the downstream components by altering the subsequent transduction of the signal. (IST-3.G.1)**
	D	Amplification describes the function of the transduction pathway, but it would not lead to an increase in reception (binding more ligands).
17	A	Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved farther away from the initial set point. Amplification occurs when the stimulus is further activated, which, in turn, initiates an additional response that produces system change. (ENE-3.C.1)
	B	**Negative feedback mechanisms maintain homeostasis for a particular condition by regulating physiological processes. If a system is perturbed, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular and cellular levels (ENE-3.B.1)**
18	A	**Positive feedback mechanisms amplify responses and processes in biological organisms. The variable initiating the response is moved farther away from the initial set point. Amplification occurs when the stimulus is further activated, which, in turn, initiates an additional response that produces system change. (ENE-3.C.1)**
	B	Negative feedback mechanisms maintain homeostasis for a particular condition by regulating physiological processes. If a system is perturbed, negative feedback mechanisms return the system back to its target set point. These processes operate at the molecular and cellular levels (ENE-3.B.1)
19	A	The cell cycle is a highly regulated series of events for the growth and reproduction of cells— (a) The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. (IST-1.B.2) Interphase is the first step of the cell cycle. During this phase, the cell prepares to divide by replicating the chromosomes and growing.
	B	The cell cycle is a highly regulated series of events for the growth and reproduction of cells— (a) The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. (IST-1.B.2) Cytokinesis is the last step of the cell cycle. This phase takes place after the mitotic phase to divide the cytoplasm creating two cells.
	C	The cell cycle is a highly regulated series of events for the growth and reproduction of cells— (a) The cell cycle consists of sequential stages of interphase (G1, S, G2), mitosis, and cytokinesis. (IST-1.B.2) Mitosis is the process of nuclear division.
	D	**Apoptosis is programmed cell death. This is not a part of the cell cycle.**
20	A	**The cell cycle is a highly regulated series of events for the growth and reproduction of cells— (b) A cell can enter a stage (G_0) where it no longer divides, but it can reenter the cell cycle in response to appropriate cues. Nondividing cells may exit the cell cycle or be held at a particular stage in the cell cycle. (IST-1.B.2)**
	B	During G_1, the cell grows in preparation for division.
	C	During G_2, the cell grows in preparation for division.
	D	During S, the DNA is synthesized (DNA replication takes place)
21	A	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(c) Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase). (IST-1.C.1)
	B	**Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(c) Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase). (IST-1.C.1)**

	C	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(c) Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase). (IST-1.C.1) (IST-1.C.1)
	D	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(c) Mitosis occurs in a sequential series of steps (prophase, metaphase, anaphase, telophase). (IST-1.C.1)
22	A	**Gametes are made through the process of Meiosis.**
	B	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(a) Mitosis plays a role in growth, tissue repair, and asexual reproduction. (IST-1.C.1)
	C	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(a) Mitosis plays a role in growth, tissue repair, and asexual reproduction. (IST-1.C.1)
	D	Mitosis is a process that ensures the transfer of a complete genome from a parent cell to two genetically identical daughter cells—(a) Mitosis plays a role in growth, tissue repair, and asexual reproduction. (IST-1.C.1)
23	A	G_1 checkpoint is in the middle of G_1 of interphase. Traditionally, this is the checkpoint that will determine if the cell divides or exits to a non-dividing state.
	B	S checkpoint is a made-up checkpoint, so this is not the answer. But, I hope you are enjoying this review guide.
	C	G2 checkpoint is at the end of G2. This is a stop to ensure that all of the chromosomes have replicated, and the cell has grown enough.
	D	**M checkpoint is during metaphase. This is a stop to ensure that all of the chromosomes are attached by microtubules to each pole prior to division. If each chromosome is not attached to each pole when the cell undergoes anaphase, there will be an unequal division of the chromosomes.**
24	A	**The level of CdK (cyclin-dependent kinase) remains high. As the cell progresses through interphase, the concentration of cyclin builds up. Once the cyclin is an appropriate level, the cyclin binds to the CdK to initiate mitosis.**
	B	CdK stands for cyclin dependent kinase – this means that the cyclin is not a precursor for CdK.
	C	Cyclin is not an inhibitor to CdK (cyclin dependent kinase) since the enzyme depends on cyclin to bind to be functional.
	D	Kinases have the function to phosphorylate. CdK does not synthesize DNA.

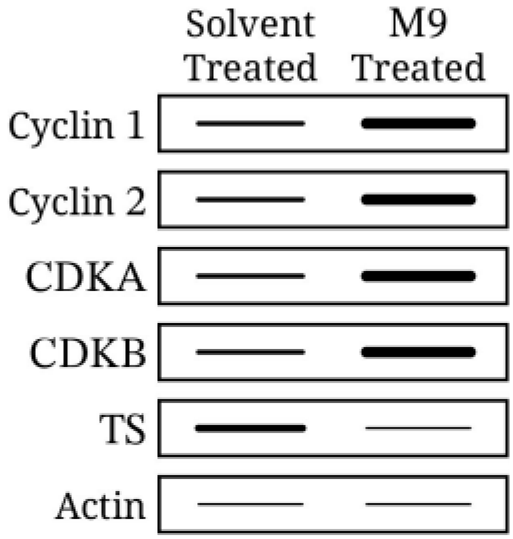
Free Response Practice

2026 CED Q2

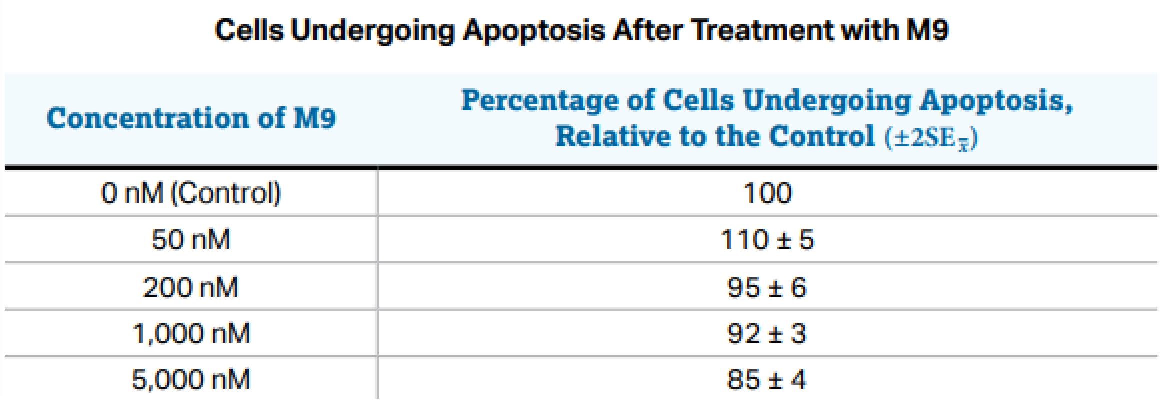
RH is a hormone that binds to the RH receptor in the plasma membrane and affects cell division. Researchers studying cancer have identified a chemical, M9, that performs the same role as RH, and they were interested in the effect of M9 on the growth of cancer cells.

In the first experiment, the researchers treated cancer cells growing in a petri dish with either solvent alone or solvent and M9. They used gel electrophoresis to determine the effect of M9 on the production of six proteins. The six proteins include two cyclin proteins (cyclin 1 and cyclin 2), two cyclin-dependent kinases (CDKA and CDKB), the tumor suppressor protein TS, and actin, a protein typically expressed equally in all cells. The thickness of the line in the figure indicates a higher concentration of protein.

Relative Amounts of Six Proteins in Cancer Cells Treated with Solvent Alone or Solvent and M9



In the second experiment, the researchers investigated the effect of M9 on apoptosis. They incubated cancer cells with solvent alone or with increasing concentrations of M9 and then determined the percentage of cells undergoing apoptosis in each treatment group relative to the control as shown in the table.



Cells Undergoing Apoptosis After Treatment with M9

Concentration of M9	Percentage of Cells Undergoing Apoptosis, Relative to the Control $(\pm 2SE_{\bar{x}})$
0 nM (Control)	100
50 nM	110 ± 5
200 nM	95 ± 6
1,000 nM	92 ± 3
5,000 nM	85 ± 4

Part A:

Describe one property of M9 that allows it to perform the same role as RH.

Part B:

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled.
ii. Based on the data in the table, **determine** which two M9 concentrations are statistically similar to one another.

Part C:

i. Using the data from the figure, **describe** the effect of M9 on the production of CDK proteins.
ii. Researchers also investigated the effect of M9 on apoptosis shown in the table. Assuming there were 115,000 cells undergoing apoptosis in the control dish, use the data in the table to **calculate** the average number of cells undergoing apoptosis in the dish treated with 5,000 nM M9.

Part D:

In addition to M9, researchers tested another chemical, MA6, which is known to block RH from binding to its receptor.

i. Predict the amount of cyclin 1 in cells treated with MA6 relative to the amount of cyclin 1 in cells treated with M9.
ii. Justify your prediction.

2025 #2

Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

(a) Many receptors are embedded in the plasma membrane. **Describe** the polarity of the portion of the receptor that is inside the membrane.

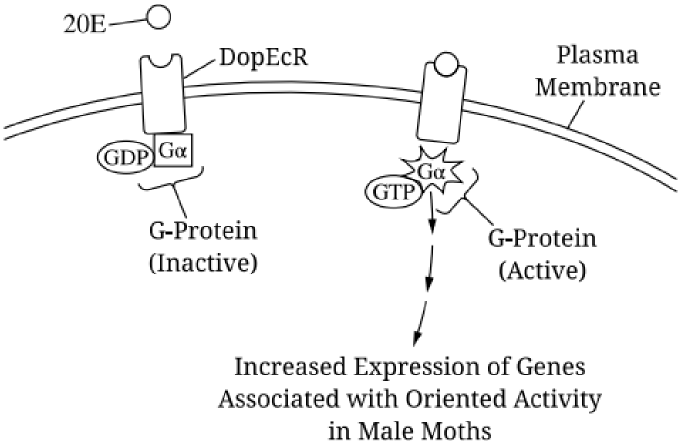
To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to the pheromone and determined the percent of total time observed that the moths engaged in general activity, defined as movement in any direction. The scientists also determined the percent of the general activity time that the moths spent in oriented activity, defined as movement toward an area of high pheromone concentration (Table 1).

Table 1. Average General and Oriented Activity in Male Moths Injected With Saline or siRNA Molecules

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
Male moths injected with saline (control solution)	95 ± 5	60 ± 4
Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR	90 ± 8	25 ± 6

DopEcR is a G protein-coupled receptor. When 20E binds to DopEcR, GTP displaces the GDP bound to the G protein, and a signaling pathway is activated. The scientists hypothesize that this leads to the transcription of genes associated with the oriented activity observed in the male moths (Figure 1).

Figure 1. A simplified model of a signaling pathway activated by the binding of 20E to its receptor, DopEcR


20E
DopEcR
Plasma Membrane
GDP
Gα
G-Protein (Inactive)
GTP
Gα
G-Protein (Active)
Increased Expression of Genes Associated with Oriented Activity in Male Moths

(b)

i. Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data in Table 1, **determine** the type of activity that was affected by inhibiting the expression of the DopEcR receptor.

(c)

i. Based on Table 1, **identify** the treatment group in which the oriented activity was greater than 50% of the general activity.

ii. The scientists studied some moths with a mutation in the gene encoding the G protein. The mutation prevents GTP from displacing the GDP bound to the G protein. Based on Figure 1, **predict** the effect of this mutation on the oriented activity in male moths exposed to the pheromone.

Expression of the gene encoding DopEcR is low in the male moths during their first few days as adults, when they are sexually immature. Gene expression rapidly increases as the moths reach sexual maturity. The scientists claim that this increase in gene expression increases the likelihood of males finding females with whom to mate.

(d)

1. Use evidence from the information provided to support the scientists' claim.
2. Based on Figure 1, explain how an inhibitor of the DopEcR pathway might serve as an effective chemical to protect crops from moth damage.

2024 #1

This question is found in Unit 5.

2023 #1

In eukaryotic microorganisms, the PHO signaling pathway regulates the expression of certain genes. These genes, *Pho* target genes, encode proteins involved in regulating phosphate homeostasis. When the level of extracellular inorganic phosphate (P_i) is high, a transcriptional activator Pho4 is phosphorylated by a complex of two proteins, Pho80–Pho85. As a result, the *Pho* target genes are not expressed. When the level of extracellular P_i is low, the activity of the Pho80–Pho85 complex is inhibited by another protein, Pho81, enabling Pho4 to induce the expression of these target genes. A simplified model of this pathway is shown in Figure 1.

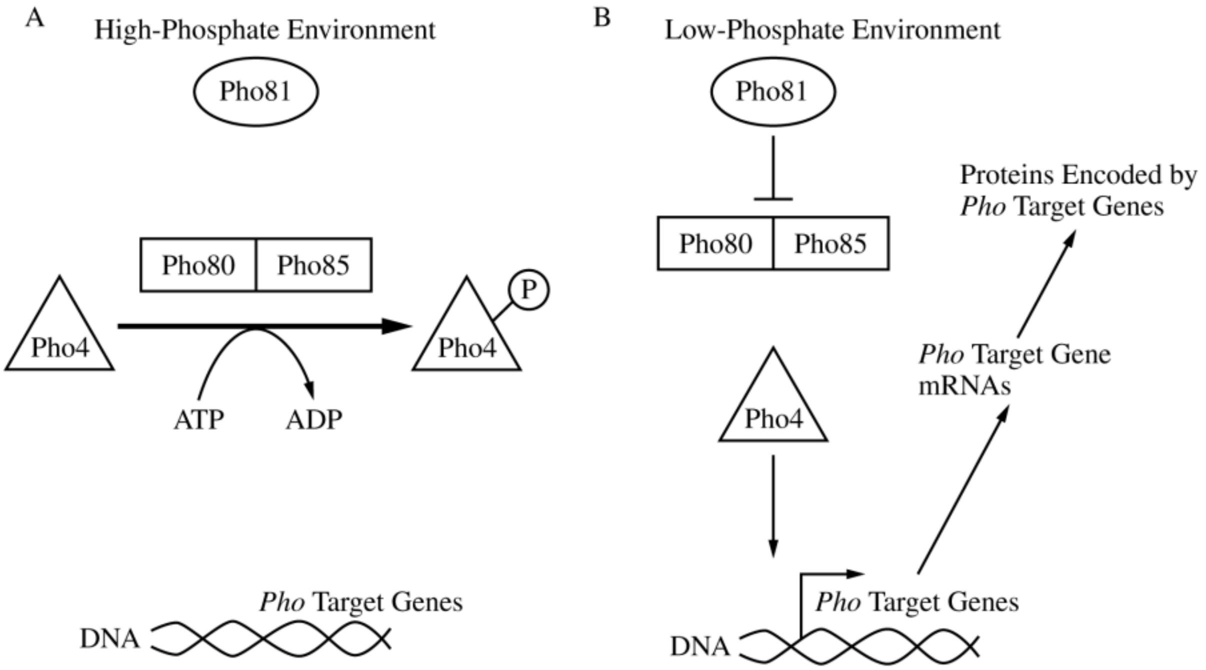

A
High-Phosphate Environment
Pho81
Pho80
Pho85
Pho4
ATP
ADP
Pho4
P
Pho Target Genes
DNA
B
Low-Phosphate Environment
Pho81
Pho80
Pho85
Proteins Encoded by Pho Target Genes
Pho Target Gene mRNAs
Pho4
Pho Target Genes
DNA

Figure 1. A simplified model of the regulation of expression of *Pho* target genes in (A) a high-phosphate (high-Pi) environment and (B) a low-phosphate (low-Pi) environment

To study the role of the different proteins in the PHO pathway, researchers used a wild-type strain of yeast to create a strain with a mutant form of Pho81 (*phio81mt*) and a strain with a mutant form of Pho4 (*pho81mt*). In each of these mutant strains, researchers measured the activity of a particular enzyme, APase, which removes phosphates from its substrates and is encoded by PHO1, a Pho target gene (Table 1). They then determined the level of PHO1 mRNA relative to that of the wild-type yeast strain, which was set to 10.

TABLE 1. APase ACTIVITY AND RELATIVE AMOUNTS OF *PHO1* mRNA IN WILD-TYPE AND MUTANT STRAINS OF YEAST IN HIGH- AND LOW-PHOSPHATE ENVIRONMENTS

Yeast Strain	Mutation	APase Activity in High-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	APase Activity in Low-Pi Environment (mU/mL/OD_{600}) $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in High-Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in Low-Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 ± 0.1	17.3 ± 0.9	0.1 ± 0.0	10 ± 2.0
pho81mt	Nonfunctional Pho81	0.4 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.9 ± 0.8
pho4mt	Nonfunctional Pho4	0.5 ± 0.0	0.8 ± 0.2	0.6 ± 0.4	0.3 ± 0.1

(a) **Describe** the effect that the addition of a charged phosphate group can have on a protein that would cause the protein to become inactive. **Explain** how a signal can be amplified during signal transduction in a pathway such as the PHO signaling pathway.

(b) Based on Table 1, **identify** a dependent variable in the researchers' experiment. **Justify** the researchers' using the wild-type strain for the creation of the mutant strains. **Justify** the researchers' using mutant strains in which only a single component of the pathway was mutated in each strain.

(c) Based on the data in Table 1, **identify** the yeast strain and growth conditions that lead to the highest relative amount of PHO1 mRNA. **Calculate** the percent change in APase activity in wild-type yeast cells in a high-P_i environment compared with that of wild-type cells in a low-P_i environment.

(d) In a follow-up experiment, researchers created a strain of yeast with a mutation that resulted in a nonfunctional Pho85 protein. Based on Figure 1, **predict** the effects of this mutation on PHO1 expression in the mutant strain in a high-P_i environment. Provide reasoning to **justify** your prediction.

2022 #1

The binding of an extracellular ligand to a G protein-coupled receptor in the plasma membrane of a cell triggers intracellular signaling (Figure 1, A). After ligand binding, GTP replaces the GDP that is bound to Gs**α** , a subunit of the G protein (Figure 1, B). This causes Gs**α** to activate other cellular proteins, including adenylyl cyclase that converts ATP to cyclic AMP (cAMP). The cAMP activates protein kinases (Figure 1, C). In cells that line the small intestine, a cAMP -activated protein kinase causes further signaling that ultimately results in the secretion of chloride ions (Cl−) from the cells. Under normal conditions, Gs**α** hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

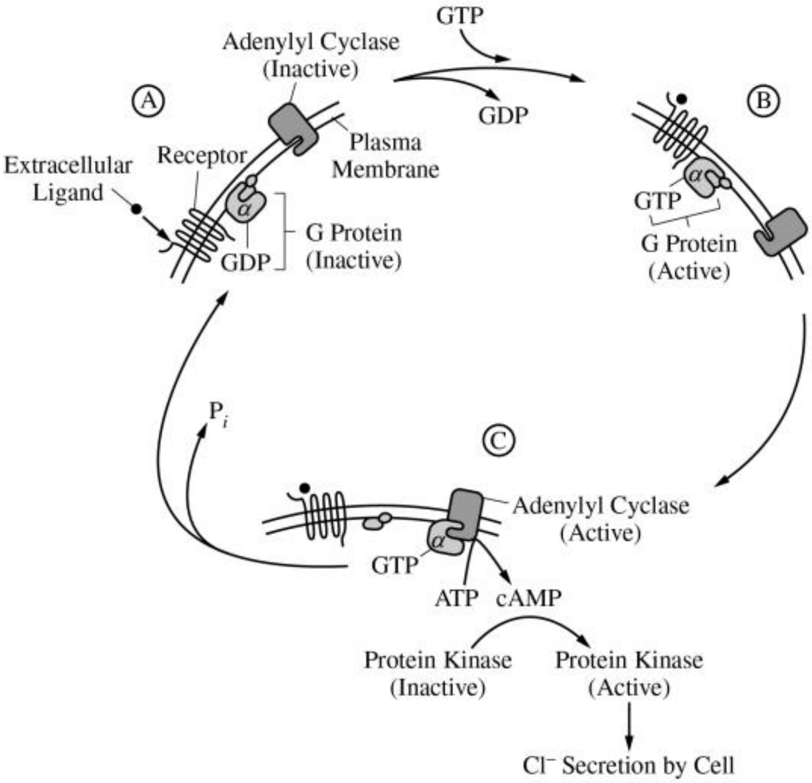

GTP
Adenylyl Cyclase (Inactive)
GDP
A
B
Extracellular Ligand
Receptor
Plasma Membrane
α
GDP
G Protein (Inactive)
GTP
G Protein (Active)
P_i
C
Adenylyl Cyclase (Active)
GTP
ATP
cAMP
Protein Kinase (Inactive)
Protein Kinase (Active)
Cl⁻ Secretion by Cell

Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

Individuals infected with the bacterium Vibrio cholerae experience severe loss of water from the body (dehydration). This is due to the effects of the bacterial cholera toxin that enters intestinal cells. Scientists studied the effects of cholera toxin on four samples of isolated intestinal cell membranes containing the G protein-related signal transduction components shown in Figure 1. GTP was added to samples II and IV only; cholera toxin was added to samples III and IV only. The scientists then measured the amount of cAMP produced by the adenylyl cyclase in each sample (Table 1).

TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	–	–	0.5
II	+	–	10.0
III	–	+	0.5
IV	+	+	127.0

present, +; absent, –

(a) **Describe** one characteristic of a membrane that requires a channel be present for chloride ions to passively cross the membrane. **Explain** why the movement of chloride ions out of intestinal cells leads to water loss.

(b) **Identify** an independent variable in the experiment. **Identify** a negative control in the experiment. **Justify** why the scientists included Sample III as a control treatment in the experiment.

(c) Based on the data, **describe** the effect of cholera toxin on the synthesis of cAMP. **Calculate** the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II.

(d) A drug is designed to bind to cholera toxin before it crosses the intestinal cell membrane. Scientists mix the drug with cholera toxin and then add this mixture and GTP to a sample of intestinal cell membranes. **Predict** the rate of cAMP production in pmol per mg adenylyl cyclase per min if the drug binds to all of the toxin. In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by Gsα . The scientists claim that cholera toxin will not cause excessive water loss from whole intestinal cells that contain the mutant adenylyl cyclase. **Justify** this claim.

2021 #1

Polycystic kidney disease (PKD) is an inherited disease that causes water loss from the body and affects cell division in the kidneys. Because water movement across cell membranes is related to ion movement, scientists investigated the role of Na^+/K^+ ATPase (also known as the sodium/potassium pump) in this disease. Ouabain, a steroid hormone, binds to the Na^+/K^+ ATPase in plasma membranes. Individuals with PKD have a genetic mutation that results in an increased binding of ouabain to the Na+/K+ ATPase. The scientists treated normal human kidney (NHK) cells and PKD cells with increasing concentrations of ouabain and measured the number of cells

(Figure 1) and the activity of the Na^+/K^+ ATPase (Figure 2) after a period of time. The scientists hypothesized that a signal transduction pathway that includes the protein kinases MEK and ERK (Figure 3) may play a role in PKD symptoms.

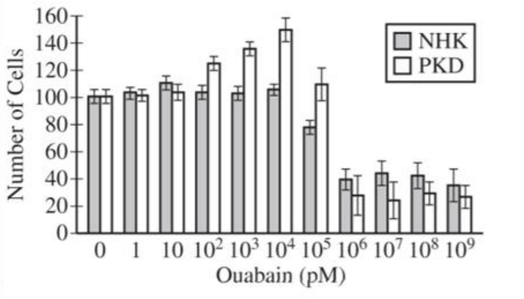


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

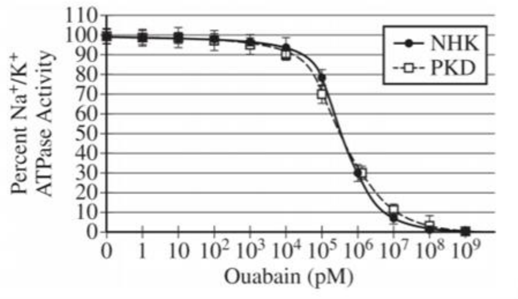


Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

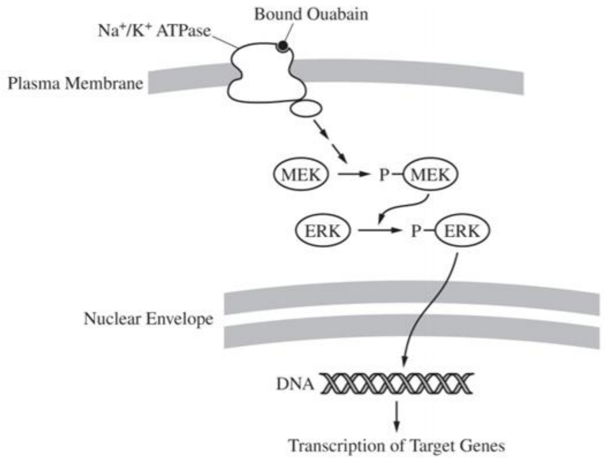


Figure 3. Signal transduction pathway hypothesized to play a role in the increased number of PKD cells

(a) **Describe** the characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane. **Explain** why ATP is required for the activity of the Na^+/K^+ ATPase.

(b) **Identify** a dependent variable in the experiment represented in Figure 1. **Justify** the use of normal human kidney (NHK) cells as a control in the experiments. **Justify** the use of a range of ouabain concentrations in the experiment represented in Figure 1.

(c) Based on the data shown in Figure 2, **describe** the relationship between the concentration of ouabain and the Na^+/K^+ ATPase activity both in normal human kidney (NHK) cells AND in PKD cells. The scientists determined that Na^+/K^+ ATPase activity in PKD cells treated with 1 pM ouabain is 150 units of ATP hydrolyzed/sec. **Calculate** the expected Na^+/K^+ ATPase activity (units/sec) in PKD cells treated with 10^6 pM ouabain.

(d) In a third experiment, the scientists added an inhibitor of phosphorylated MEK (pMEK) to the PKD cells exposed to 10^4 pM ouabain. Based on Figure 3, **predict** the change in the relative ratio of ERK and pERK in ouabain-treated PKD cells with the inhibitor compared with ouabain-treated PKD cells without the inhibitor. Provide reasoning to **justify** your prediction. Using the data in Figure 1 AND the signal transduction pathway represented in Figure 3, **explain** how the concentration of cyclin proteins may increase in PKD cells treated with 10^4 pM ouabain.

2019 #4

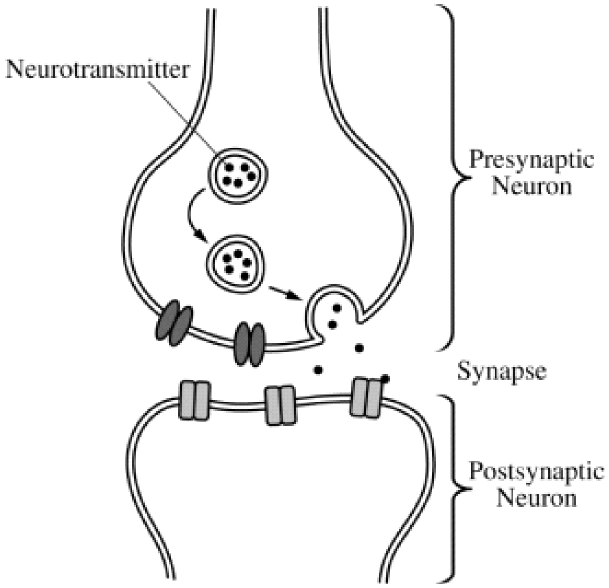


Figure 1. Release of neurotransmitters into the synapse in response to an action potential

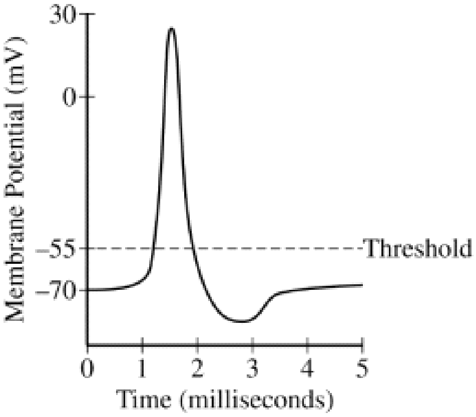


Figure 2. Model of a typical action potential in a neuron

Acetylcholine is a neurotransmitter that can activate an action potential in a postsynaptic neuron (Figures 1 and 2). A researcher is investigating the effect of a particular neurotoxin that causes the amount of acetylcholine released from presynaptic neurons to increase.

(a) **Describe** the immediate effect of the neurotoxin on the number of action potentials in a postsynaptic neuron. **Predict** whether the maximum membrane potential of the postsynaptic neuron will increase, decrease, or stay the same.

(b) The researcher proposes two models, A and B, for using acetylcholinesterase (AChE), an enzyme that degrades acetylcholine, to prevent the effect of the neurotoxin. In model A, AChE is added to the synapse. In model B, AChE is added to the cytoplasm of the postsynaptic cell. **Predict** the effectiveness of EACH proposed model. **Provide reasoning** to support your predictions.

2018 #2

Some pathogenic bacteria enter cells, replicate, and spread to other cells, causing illness in the host organism. Host cells respond to these infections in a number of ways, one of which involves activating particular enzymatic pathways (Figure 1). Cells normally produce a steady supply of inactive caspase-1 protein. In response to intracellular pathogens, the inactive caspase-1 is cleaved and forms an active caspase-1 (step 1). Active caspase-1 can cleave two other proteins. When caspase-1 cleaves an inactive interleukin (step 2), the active portion of interleukin is released from the cell. An interleukin is a signaling molecule that can activate the immune response. When caspase-1 cleaves gasdermin (step 3), the N-terminal portions of several gasdermin proteins associate in the cell membrane to form large, nonspecific pores.

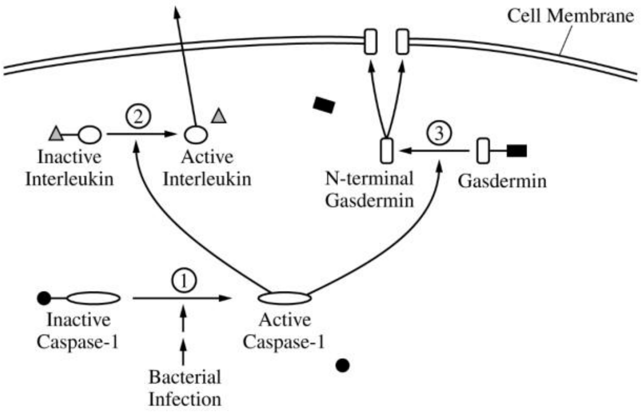


Figure 1. Cellular response to infection by pathogenic bacteria

Researchers created the model in Figure 1 using data from cell fractionation studies. In the experiments, various parts of the cell were separated into fractions by mechanical and chemical methods. Specific proteins known to be located in different parts of the cell were used as markers to determine the location of other proteins. The table below shows the presence of known proteins in specific cellular fractions.

CELL FRACTIONS CONTAINING DIFFERENT CELLULAR PROTEINS

	Aconitase (Krebs cycle protein)	DNA polymerase	GAPDH (glycolytic protein)	Sodium-potassium pump	NF-κB (Immune response protein)
Whole cell sample	+	+	+	+	+
Fraction 1	+				
Fraction 2		+			+
Fraction 3			+		+
Fraction 4				+	

+ = presence of protein

(a) **Describe** the effect of inhibiting step 3 on the formation of pores AND on the release of interleukin from the cell.

(b) **Make a claim** about how cleaving inactive caspase-1 results in activation of caspase-1. A student claims that preinfection production of inactive precursors shortens the response time of a cell to a bacterial infection. **Provide ONE reason** to support the student's claim.

(c) A student claims that the NF-kB protein is located in the cytoplasm until the protein is needed for transcription. **Justify** the student's claim with evidence. **Identify** TWO fractions where N-terminal gasdermin would be found in cells infected with pathogenic bacteria.

(d) **Describe** the most likely effect of gasdermin pore formation on water balance in the cell in a hypotonic environment.

(e) **Explain** how gasdermin pore formation AND interleukin release contribute to an organism's defense against a bacterial pathogen.

2018 #8

Acetylcholine receptor (AChR) proteins are found at the synapse between neurons and skeletal muscle cells. Acetylcholine released from neurons binds to a specific site on the receptor proteins, which causes an ion channel in the receptors to open and allow sodium ions (Na^+) to enter muscle cells. The resulting depolarization of muscle cells initiates muscle contractions. Another molecule, nicotine, can also bind to certain types of AChR proteins and activate the receptors.

A researcher is investigating two different types of AChR proteins: type 1 and type 2. To determine which stimuli activate the receptors, the researcher exposes muscle cells expressing the different types of receptor proteins to stimuli and observes the result indicated in Table 1.

TABLE 1. RESPONSE OF AChR PROTEINS TO DIFFERENT STIMULI

AChR Protein Type	Acetylcholine	Nicotine
Type 1	+	+
Type 2	+	–

+ indicates activation
– indicates no activation

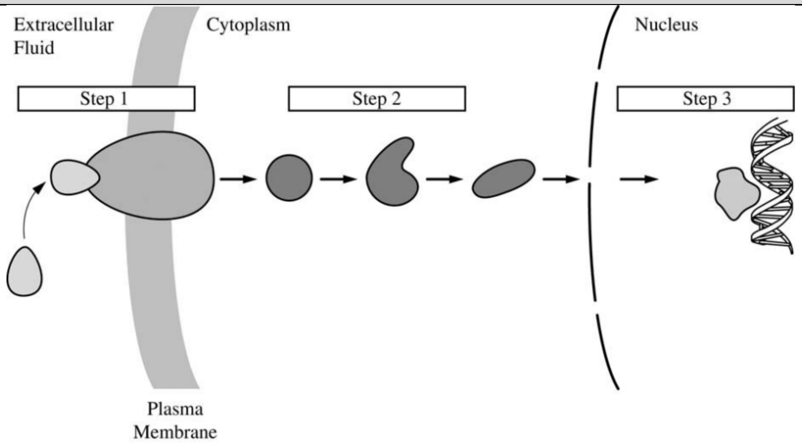
(a) **Describe** the difference in the structure AND function between AChR type 1 and AChR type 2.

(b) Acetylcholinesterase is an enzyme that breaks down acetylcholine in the synapse. **Describe** the effect of inhibiting acetylcholinesterase on the muscle cells with AChR type 2.

2015 #7a

This question is in Unit 6.

2013 #8

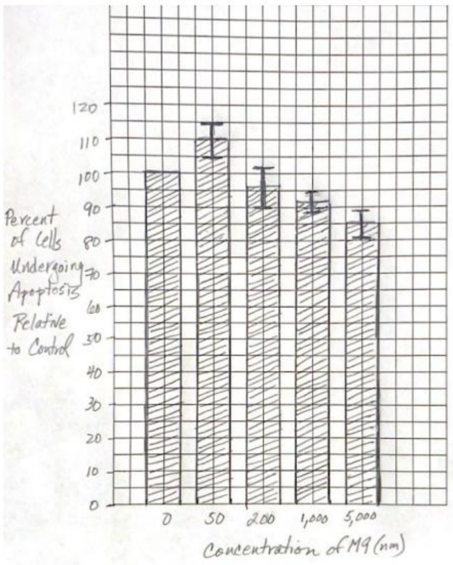


The figure above represents a generalized hormone-signaling pathway. Briefly **explain** the role of each numbered step in regulating target gene expression.

Free Response Scoring Guidelines

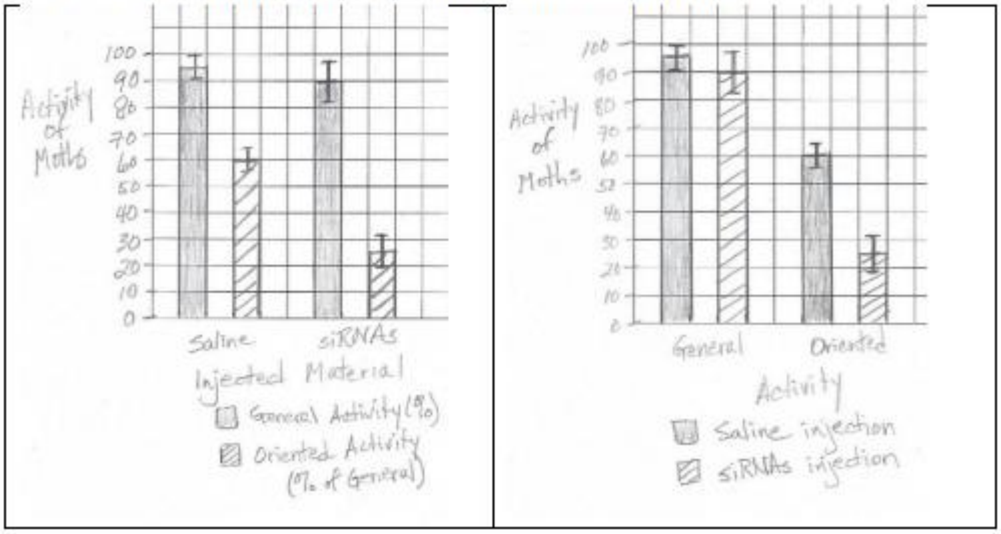
2026 CED Q2

Course Content	Practice and Skill
4.2: Introduction to Signal Transduction • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response. 4.3: Signal Transduction Pathways • 4.3.A: Describe the different types of cellular responses elicited by a signal transduction pathway. • 4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway. 4.6: Regulation of Cell Cycle • 4.6.A: Describe the role of checkpoints in regulating the cell cycle. • 4.6.B: Describe the effects of disruptions to the cell cycle on the cell or organism.	1.A: Describe biological concepts and processes. 4.A: Construct a graph to represent the data 4.B: Describe data from a table or graph 5.A: Perform mathematical calculations 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	▪ M9 has a structure that can bind to and activate the RH receptor.
(b)	i. Sample response:  ▪ Data are represented in a bar graph. ▪ Data and error bars are accurately plotted. ▪ Graph includes labeled axes and legend. II. ▪ 200 nM and 1,000 nM
(c)	i.

	▪ M9 causes the production of CDK proteins to increase. ii. ▪ 97,750 (Acceptable range is 93,150 - 102,350)
(d)	i. ▪ The amount of cyclin 1 will be lower in cells treated with MA6 (than in cells treated with M9). ii. ▪ If the signal cannot bind to the receptor, the pathway that leads to an increase in cyclin 1 expression cannot be activated.

<table>
<tr><th colspan="2">2025 #2</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>1.7: Proteins
• 1.7.A*: Describe the structure and function of proteins
4.3: Signal Transduction Pathways
• 4.3.A*: Describe the different types of cellular responses elicited by a signal transduction pathway.
• 4.3.B*: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.</td><td>1.A: Describe biological concepts and processes.
4.A: Construct a graph to represent the data
4.B: Describe data from a table or graph
6.B: Support a claim with evidence from biological principles, concepts, processes, and data.
6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.</td></tr>
</table>

<table>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>Examples of acceptable responses may include the following:
• (The portion of the receptor inside the membrane) is nonpolar.
• (The portion of the receptor inside the membrane) is hydrophobic.</td></tr>
<tr><td>(b)</td><td>i.
• Data are represented in a bar/modified bar graph.
• Examples of acceptable responses may include the following:

• Data and error bars are accurately plotted.</td></tr>
</table>

	• Graph is appropriately labeled. II. • Oriented activity (was affected).
(c)	i. Examples of acceptable responses may include the following: • The control/saline-treated group • Male moths injected with saline/control solution ii. • (The moths will show) decreased (oriented) activity.
(d)	i. Examples of acceptable responses may include the following: • (Increased expression of DopEcR) will increase oriented activity (and the moths' ability to find a mate). • (An increase in DopEcR expression) will enable the binding of 20E to more receptors. • (An increase in DopEcR expression) will make the males more sensitive to pheromones from the females. • (An increase in DopEcR expression) will enable the binding of 20E to more receptors and will make the males more sensitive to pheromones from the females. ii. • (An inhibitor of the pathway) will reduce oriented activity/expression of genes associated with oriented activity and therefore decrease mating/population growth.

Scoring Statistics

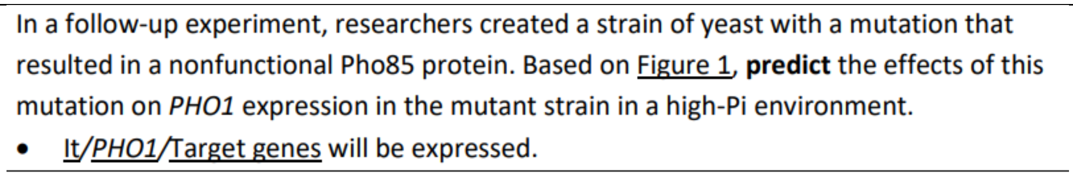
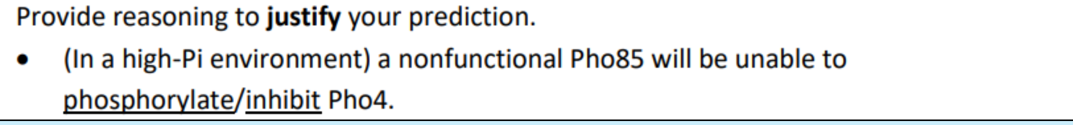
	Max Points:	**Mean Score:**
Point A1	1.0	0.50
Point B1	1.0	0.88
Point B2	1.0	0.66
Point B3	1.0	0.63
Point B4	1.0	0.72
Point C1	1.0	0.75
Point C2	1.0	0.47
Point D1	1.0	0.34
Point D2	1.0	0.21
Overall Mean Score: 5.17		

2023 #1

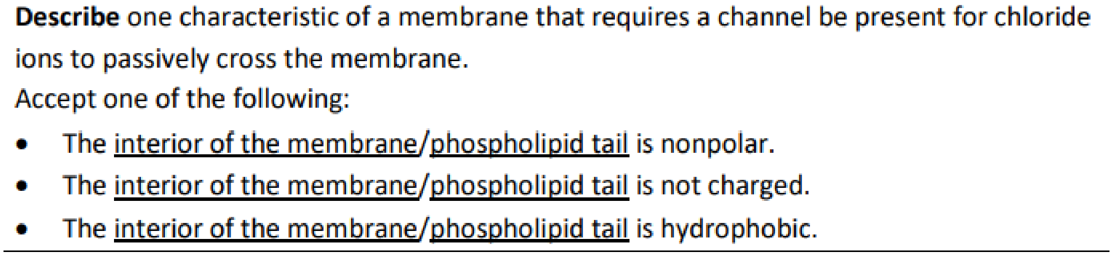
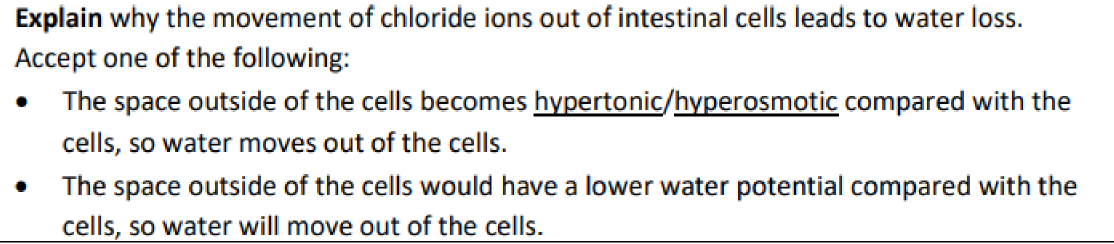
Course Content	Practice and Skill
1.7: Proteins • 1.7.A: Describe the structure and function of proteins. 4.2: Introduction to Signal Transduction • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 3.C: Identify experimental procedures that align with the question 4.B: Describe data from a table or graph 5.A: Perform mathematical calculations

4.3: Signal Transduction Pathways • 4.3.A: Describe the different types of cellular responses elicited by a signal transduction pathway. • 4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.	6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	**Describe** the effect the addition of a charged phosphate group can have on a protein that would cause the protein to become inactive. • It changes the structure/shape of the protein. **Explain** how a signal can be amplified during signal transduction in a pathway such as the PHO signaling pathway. • Each enzyme (in a signal transduction pathway) can act on many copies of a protein.
(b)	Based on Table 1, **identify** a dependent variable in the researchers' experiment. Accept one of the following: • APase activity • (Relative) amount of *PHO1* (mRNA) **Justify** the researchers' using the wild-type strain for the creation of the mutant strains. Accept one of the following: • It ensures that any observed differences (in experimental results) between the strains are due to the introduced mutations (and not to other genetic differences between the yeast strains). • It ensures that the strains are genetically identical except for the introduced mutations. **Justify** the researchers' using mutant strains in which only a single component of the pathway was mutated in each strain. Accept one of the following: • It allows them to test the effect of each mutation separately. • It allows them to (better) determine which component is responsible for any observed differences.
(c)	Based on the data in Table 1, **identify** the yeast strain and growth conditions that lead to the highest relative amount of *PHO1* mRNA. • Wild-type yeast in a low-Pi environment **Calculate** the percent change in APase activity in wild-type yeast cells in a high-Pi environment compared with that of wild-type cells in a low-Pi environment. Accept one of the following: • 3,360% [(17.3–0.5)/0.5 × 100%] • -97% [(0.5–17.3)/17.3 × 100%]

(d)	 In a follow-up experiment, researchers created a strain of yeast with a mutation that resulted in a nonfunctional Pho85 protein. Based on Figure 1, **predict** the effects of this mutation on *PHO1* expression in the mutant strain in a high-Pi environment. • It/*PHO1*/Target genes will be expressed.  Provide reasoning to **justify** your prediction. • (In a high-Pi environment) a nonfunctional Pho85 will be unable to phosphorylate/inhibit Pho4.
Scoring Statistics	
Mean: 2.80	Standard Deviation: 2.25

2022 #1	
Course Content	Practice and Skill
2.4: Membrane Permeability • 2.4.A: Explain how the structure of biological membranes influences selective permeability. 2.7: Tonicity and Osmoregulation • 2.7.A: Explain how concentration gradients affect the movement of molecules across membranes. 4.2: Introduction to Signal Transduction • 4.2.A: Describe the components of a signal transduction pathway. • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 3.C: Identify experimental procedures that align with the question 3.B: State the null hypothesis or predict the results of an experiment. 4.B: Describe data from a table or graph 5.A: Perform mathematical calculations, including: i. mathematical equations in the curriculum ii. means iii. rates iv. ratios v. percentages and percent changes 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

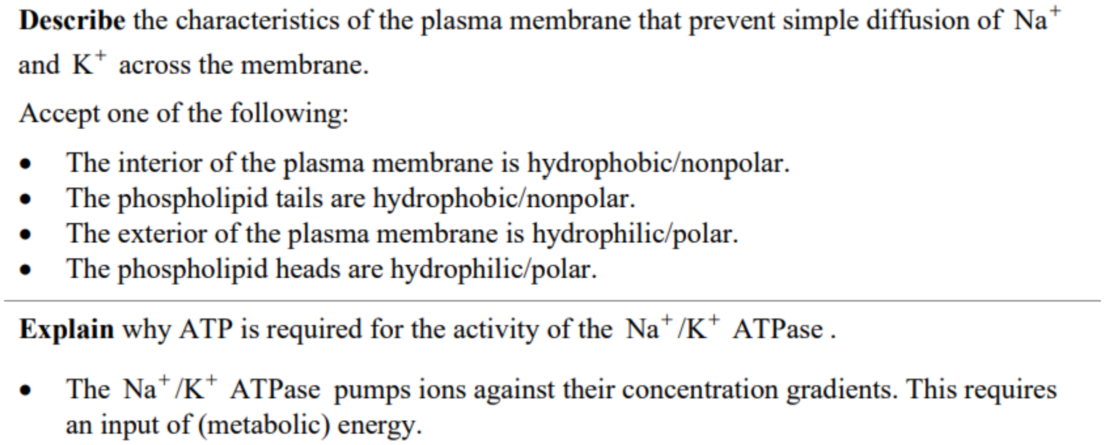
Part	Scoring Guidelines
(a)	 **Describe** one characteristic of a membrane that requires a channel be present for chloride ions to passively cross the membrane. Accept one of the following: • The interior of the membrane/phospholipid tail is nonpolar. • The interior of the membrane/phospholipid tail is not charged. • The interior of the membrane/phospholipid tail is hydrophobic.  **Explain** why the movement of chloride ions out of intestinal cells leads to water loss. Accept one of the following: • The space outside of the cells becomes hypertonic/hyperosmotic compared with the cells, so water moves out of the cells. • The space outside of the cells would have a lower water potential compared with the cells, so water will move out of the cells.

(b)	**Identify** an independent variable in the experiment. Accept one of the following: • The presence or absence of cholera toxin • The presence or absence of GTP
	Identify a negative control in the experiment. Accept one of the following: • The sample lacking both cholera toxin and GTP /sample I • The samples that lack cholera toxin /samples I and II • The sample that lacks cholera toxin but contains GTP /sample II • The samples that lack GTP /samples I and III
	Justify why the scientists included Sample III as a control treatment in the experiment. Accept one of the following: • (Sample III serves as a control) to compare cAMP production with that of the sample having cholera toxin and GTP /sample IV. • Comparing sample III and sample IV enables the scientists to evaluate whether the activity of cholera toxin requires GTP/acts via the G protein pathway.
(c)	Based on the data, **describe** the effect of cholera toxin on the synthesis of cAMP. Accept one of the following: • Cholera toxin increases the production of cAMP in the presence of GTP (IV vs II). • Cholera toxin has no effect on the production of cAMP in the absence of GTP (III vs I).
	Calculate the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II. • 1,170% [(127−10)/10 = 11.7 × 100]
(d)	A drug is designed to bind to cholera toxin and prevent the toxin from crossing the intestinal cell membrane. Scientists mix the drug with cholera toxin and then add this mixture and GTP to a sample of intestinal cell membranes. **Predict** the rate of cAMP production in pmol per mg adenylyl cyclase per min if the drug binds to all of the toxin. • The rate will be 10 (pmol per mg adenyl cyclase per min).
	In a separate experiment, scientists engineer a mutant adenylyl cyclase that cannot be activated by $Gs\alpha$. The scientists claim that cholera toxin will not cause excessive water loss from whole intestinal cells that contain the mutant adenylyl cyclase. **Justify** this claim. • (Even in the presence of the toxin) cAMP will not be produced (by this pathway), the protein kinases will not be activated, and Cl^- ions will not be secreted (and less water will leave the intestinal cells).

Scoring Statistics	
Mean: 2.26	Standard Deviation: 1.83

2021 #1

Course Content	Practice and Skill
2.3: Plasma Membrane • 2.3.A: Describe the roles of each of the components of the cell membrane in maintaining the internal environment of the cell. 2.6: Facilitated Diffusion • 2.6.A: Explain how the structure of a molecule affects its ability to pass through the plasma membrane. 4.2: Introduction to Signal Transduction • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response. 4.3: Signal Transduction Pathways • 4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question

Part	Scoring Guidelines
(a)	 **Describe** the characteristics of the plasma membrane that prevent simple diffusion of Na^+ and K^+ across the membrane. Accept one of the following: • The interior of the plasma membrane is hydrophobic/nonpolar. • The phospholipid tails are hydrophobic/nonpolar. • The exterior of the plasma membrane is hydrophilic/polar. • The phospholipid heads are hydrophilic/polar. **Explain** why ATP is required for the activity of the Na^+/K^+ ATPase . • The Na^+/K^+ ATPase pumps ions against their concentration gradients. This requires an input of (metabolic) energy.

(b)	**Identify** a dependent variable in the experiment represented in Figure 1. • The number of cells **Justify** the use of normal human kidney NHK cells as a control in the experiments. Accept one of the following: • It allows the scientists to determine the effect of PKD on the cells' responses to (various concentrations of) ouabain. • It allows the scientists to compare the responses of PKD cells and normal cells (to ouabain). **Justify** the use of a range of ouabain concentrations in the experiment represented in Figure 1. Accept one of the following: • The scientists need to determine whether different concentrations have different effects on the cell numbers. • The scientists did not know at which concentration of ouabain there would be an effect.
(c)	Based on the data shown in Figure 2, **describe** the relationship between the concentration of ouabain and the Na^+/K^+ ATPase activity both in normal human kidney (NHK) cells AND in PKD cells. Accept one of the following: • Increasing concentrations of ouabain result in decreasing ATPase activity (in both types of cells). • There is an inverse relationship/negative correlation between the concentration of ouabain and the ATPase activity (in both types of cells). The scientists determined that Na^+/K^+ ATPase activity in PKD cells treated with 1 pM ouabain is 150 units of ATP hydrolyzed/sec. **Calculate** the expected Na^+/K^+ ATPase activity (units/sec) in PKD cells treated with 10^6 pM ouabain. • 45 (Accept between 40 and 50)

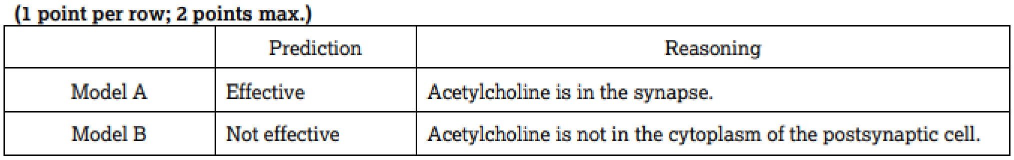
(d)	In a third experiment, the scientists added an inhibitor of phosphorylated MEK (pMEK) to the PKD cells exposed to 10^4 pM ouabain. Based on Figure 3, **predict** the change in the relative ratio of ERK to pERK in ouabain-treated PKD cells with the inhibitor compared with ouabain-treated PKD cells without the inhibitor. Accept one of the following: • Option 1: The ratio of ERK to pERK will increase in the cells with the inhibitor. • Option 2: The ratio of ERK to pERK will stay the same in the cells with the inhibitor.
	Provide reasoning to **justify** your prediction. • The justification must indicate that the pMEK inhibitor blocks further phosphorylation of ERK AND one of the following: Option 1: • The amount of pERK will not increase as it does in cells without the inhibitor. • The amount of ERK will not decrease as it does in cells without the inhibitor. • The cell continues to synthesize ERK. • Phosphorylated ERK is being dephosphorylated to ERK. Option 2: • No additional ERK is synthesized/pERK is not being dephosphorylated.
	Using the data in Figure 1 AND the signal transduction pathway represented in Figure 3, **explain** why the concentration of cyclin proteins may increase in PKD cells treated with 10^4 pM ouabain. • The cell number increases to a maximum at 10^4 pM ouabain. The signaling pathway stimulates transcription of genes involved in cell division. The target genes likely include those for cyclins because cyclins regulate the cell cycle.

Scoring Statistics	
Mean: 3.68	Standard Deviation: 2.28

2019 #4

Course Content	Practice and Skill
4.2: Introduction to Signal Transduction • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.	2.A: Describe characteristics of visual representations of biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	**Description (1 point)** • It will increase the number of action potentials. **Prediction (1 point)** • It will stay the same.

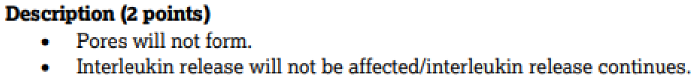
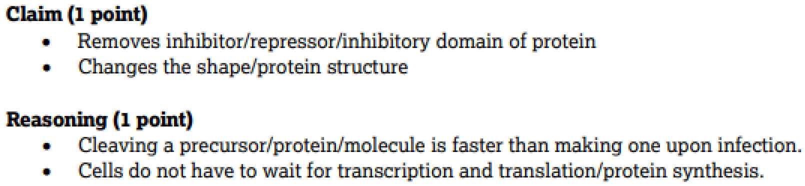
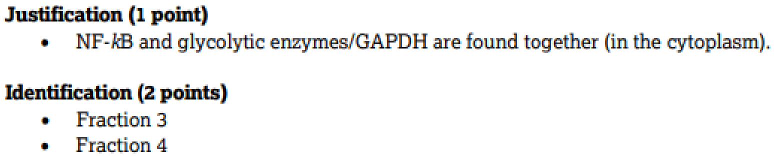
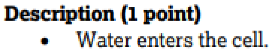
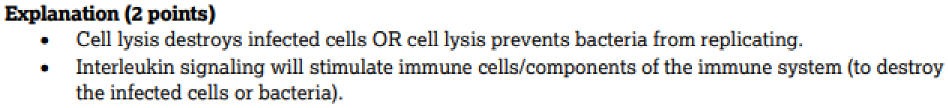
(b)	 **(1 point per row; 2 points max.)**

	Prediction	Reasoning
Model A	Effective	Acetylcholine is in the synapse.
Model B	Not effective	Acetylcholine is not in the cytoplasm of the postsynaptic cell.

Scoring Statistics	
Mean: 1.46	Standard Deviation: 1.25

2018 #2

Course Content	Practice and Skill
2.7: Tonicity and Osmoregulation • 2.7.A: Explain how concentration gradients affect the movement of molecules across membranes. 4.2: Introduction to Signal Transduction • 4.2.A: Describe the components of a signal transduction pathway. • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response. 4.3: Signal Transduction Pathways • 4.3.B: Explain how a change in the structure of any signaling molecule affects the activity of the signaling pathway.	2.A: Describe characteristics of visual representations of biological concepts and processes. 2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 6.A: Make a scientific claim. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	 **Description (2 points)** • Pores will not form. • Interleukin release will not be affected/interleukin release continues.
(b)	 **Claim (1 point)** • Removes inhibitor/repressor/inhibitory domain of protein • Changes the shape/protein structure **Reasoning (1 point)** • Cleaving a precursor/protein/molecule is faster than making one upon infection. • Cells do not have to wait for transcription and translation/protein synthesis.
(c)	 **Justification (1 point)** • NF-*k*B and glycolytic enzymes/GAPDH are found together (in the cytoplasm). **Identification (2 points)** • Fraction 3 • Fraction 4
(d)	 **Description (1 point)** • Water enters the cell.
(e)	 **Explanation (2 points)** • Cell lysis destroys infected cells OR cell lysis prevents bacteria from replicating. • Interleukin signaling will stimulate immune cells/components of the immune system (to destroy the infected cells or bacteria).

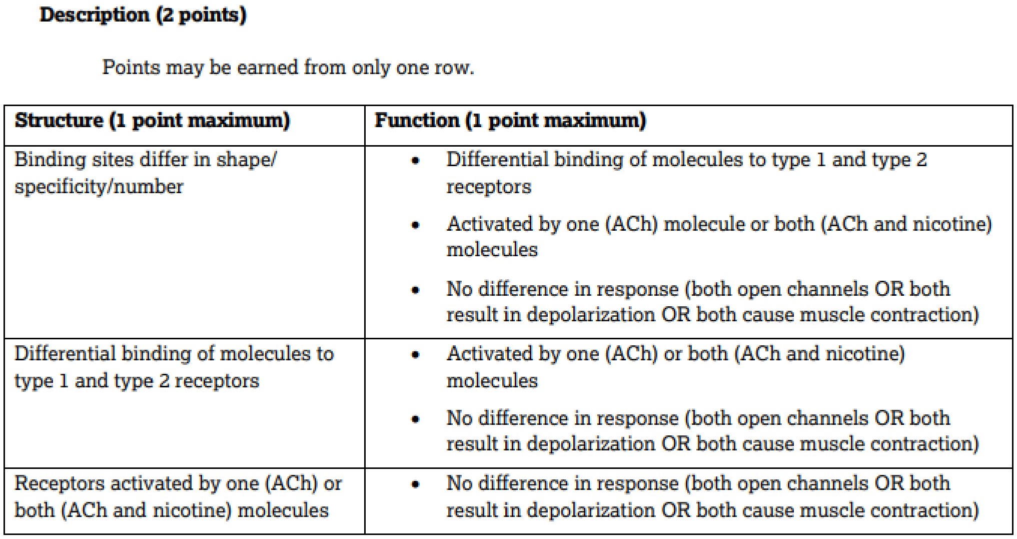
Scoring Statistics	
Mean: 2.68	Standard Deviation: 2.33

2018 #8

Course Content	Practice and Skill
4.3: Signal Transduction Pathways • 4.3.A: Describe the different types of cellular responses elicited by a signal transduction pathway.	2.A: Describe characteristics of visual representations of biological concepts and processes.

Part	Scoring Guidelines
(a)	See below
(b)	See below

(a)

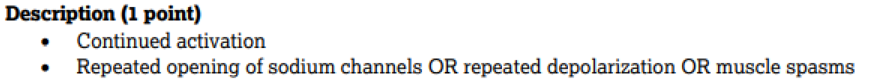


Description (2 points)

Points may be earned from only one row.

Structure (1 point maximum)	**Function (1 point maximum)**
Binding sites differ in shape/ specificity/number	• Differential binding of molecules to type 1 and type 2 receptors • Activated by one (ACh) molecule or both (ACh and nicotine) molecules • No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Differential binding of molecules to type 1 and type 2 receptors	• Activated by one (ACh) or both (ACh and nicotine) molecules • No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)
Receptors activated by one (ACh) or both (ACh and nicotine) molecules	• No difference in response (both open channels OR both result in depolarization OR both cause muscle contraction)

(b)



Description (1 point)

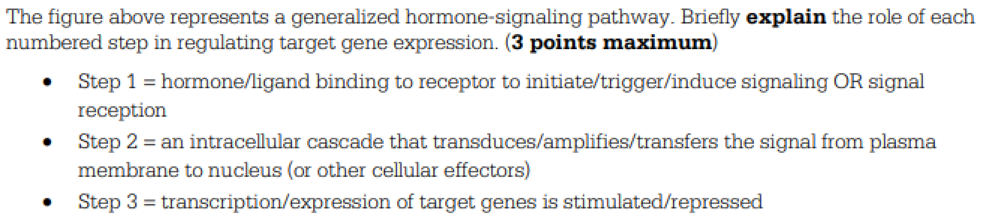
- Continued activation
- Repeated opening of sodium channels OR repeated depolarization OR muscle spasms

Scoring Statistics	
Mean: 0.95	Standard Deviation: 1.00

2013 #8

Course Content	Practice and Skill
4.2: Introduction to Signal Transduction • 4.2.B: Describe the role of components of a signal transduction pathway in producing a cellular response.	2.A: Describe characteristics of visual representations of biological concepts and processes.

Part | Scoring Guidelines



The figure above represents a generalized hormone-signaling pathway. Briefly **explain** the role of each numbered step in regulating target gene expression. (**3 points maximum**)

- Step 1 = hormone/ligand binding to receptor to initiate/trigger/induce signaling OR signal reception
- Step 2 = an intracellular cascade that transduces/amplifies/transfers the signal from plasma membrane to nucleus (or other cellular effectors)
- Step 3 = transcription/expression of target genes is stimulated/repressed

Scoring Statistics	
Mean: 0.90	Standard Deviation: 1.11

Unit 5: Heredity

Topic	**Learning Objective(s)**
5.1 **Meiosis**	**5.1.A:** Explain how meiosis results in the transmission of chromosomes from one generation to the next. **5.1.B:** Describe similarities and differences between the phases and outcomes of mitosis and meiosis.
5.2 **Meiosis and Genetic Diversity**	**5.2.A:** Explain how the process of meiosis generates genetic diversity.
5.3 **Mendelian Genetics**	**5.3.A:** Explain the inheritance of genes and traits as described by Mendel's laws.
5.4 **Non-Mendelian Genetics**	**5.4.A:** Explain deviations from Mendel's model of the inheritance of traits.
5.5 **Environmental Effects on Phenotype**	**5.5.A:** Explain how the same genotype can result in multiple phenotypes under different environmental conditions.

Additional Resources

Unit 5 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

Topic 5.1 Meiosis

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
5.1.A: Explain how meiosis results in the transmission of chromosomes from one generation to the next.	
5.1.A.1: Meiosis is a process that ensures the formation of haploid gamete cells, sometimes referred to as daughter cells, in sexually reproducing diploid organisms.	☐ I can explain the ways that meiosis results in the movement of chromosomes from one generation to the next. ☐ I can describe the process of meiosis. ☐ I can describe the function of meiosis. ☐ I can explain the ways to reduce the chromosome number in meiosis from one generation to the next.

1. What is meiosis?
2. How do the parent cells compare to the daughter cells in meiosis?
3. What is the function of meiosis?
4. How is the chromosome number reduced through the process of meiosis from one generation to the next.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
5.1.A: Explain how meiosis results in the transmission of chromosomes from one generation to the next.	
5.1.A.2: Meiosis I involves the following steps: i. Prophase I: Homologous chromosomes pair up and condense, synapsis occurs and then chiasmata may form, meiotic spindle begins to form, centrosomes move to opposite poles of the cell, and the nuclear envelope breaks down. ii. Metaphase I: Meiotic spindle fibers align homologous pairs of chromosomes along the equator of the cell at the metaphase plate. iii. Anaphase I: Homologous chromosomes separate, while sister chromatids remain attached, as meiotic spindle fibers pull chromosomes toward poles. iv. Telophase I: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or cell plate (plant cell) forms, and cytokinesis occurs. Two haploid	☐ I can explain the phases of meiosis I. ☐ I can describe prophase I. ☐ I can describe metaphase I. ☐ I can describe anaphase I. ☐ I can describe telophase I. ☐ I can explain the role of meiosis I.

daughter cells are formed (at the end of meiosis I).	

5. What are the FOUR phases of meiosis I?
    a. Describe each of the phases of meiosis I?
6. What is the role of meiosis I?
7. What is the ploidy of the daughter cells after meiosis I?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.1.A: Explain how meiosis results in the transmission of chromosomes from one generation to the next.</td></tr>
<tr><td>5.1.A.3: Meiosis II involves the following steps:
i. Prophase II: Meiotic spindle forms; sister chromatids connected at the centromere attach to meiotic spindle.
ii. Metaphase II: Chromosomes align along the metaphase plate; the kinetochore of each chromatid is attached to a microtubule extending from the poles.
iii. Anaphase II: Proteins at the centromeres break down, and sister chromatids are pulled apart and toward opposite poles in the cell.
iv. Telophase II: Meiotic spindle breaks down, a new nuclear envelope develops, a cleavage furrow (animal cell) or a cell plate (plant cell) forms, chromatids begin to decondense, and cytokinesis occurs. Four haploid daughter cells are formed, each with an unduplicated chromatid.</td><td>☐ I can explain the phases of meiosis II.
☐ I can describe prophase II.
☐ I can describe metaphase II.
☐ I can describe anaphase II.
☐ I can describe telophase II.
☐ I can explain the role of meiosis II.</td></tr>
</table>

8. What are the FOUR phases of meiosis II?
    a. Describe each of the phases of meiosis II?
9. What is the role of meiosis II?
10. What is the ploidy of the daughter cells after meiosis II?
11. Identify three differences between meiosis I and meiosis II,
12. Identify what part of meiosis results in the reduction of chromosome number.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
5.1.B: Describe similarities and differences between the phases and outcomes of mitosis and meiosis.	
5.1.B.1: Mitosis and meiosis are similar in the use of a spindle apparatus to move chromosomes but differ in the number of cells produced and the genetic content of the daughter cells.	☐ I can describe the similarities between the phases of mitosis and meiosis. ☐ I can describe the differences between the phases of mitosis and meiosis. ☐ I can describe the similarities between the outcomes of mitosis and meiosis. ☐ I can describe the differences between the outcomes of mitosis and meiosis.

13. Using the following chart, compare and contrast mitosis and meiosis:

Property	Mitosis	Meiosis
Parent Cell Ploidy		
Phases involved		
Rounds of DNA Replication		
Rounds of Nuclear Division		
Number of Daughter Cells		
Daughter Cell Ploidy		
Independent Assortment (if yes, what phase)		
Crossing Over (if yes, what phase)		

14. Describe the daughter cells resulting from mitosis.
15. Describe the daughter cells resulting from meiosis.
16. Identify three similarities between mitosis and meiosis.
17. Identify three differences between mitosis and meiosis.

Topic 5.2: Meiosis and Genetic Diversity

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.2.A: Explain how the process of meiosis generates genetic diversity.</td></tr>
<tr><td>5.2.A.1: Correct separation of the homologous chromosomes in meiosis I and sister chromatids in meiosis II ensures that each gamete receives a haploid (1n) set of chromosomes that comprises an assortment of both maternal and paternal chromosomes. When incorrect separation occurs (nondisjunction), gametes are no longer haploid.</td><td>☐ I can explain the ways that meiosis generates genetic diversity.
☐ I can identify the material being separated in meiosis I vs meiosis II.
☐ I can explain how the homologous chromosomes separate during anaphase I.
☐ I can explain how the sister chromatids separate during anaphase II.
☐ I can explain how daughter cells receive both maternal and paternal chromosomes.
☐ I can explain why the daughter cells after meiosis I are haploid.
☐ I can explain what happens when incorrect separation occurs.
☐ I can describe nondisjunction.
☐ I can predict the results of nondisjunction.</td></tr>
</table>

1. How does meiosis generate genetic diversity?
2. Describe the material separated during meiosis I vs meiosis II.
    a. How does this segregation of this material affect the ploidy of the daughter cells?
3. Describe the process that allows for homologous chromosomes to segregate during meiosis I.
4. Describe the process that allows for sister chromatids to segregate during meiosis II.
5. How do daughter cells receive both maternal and paternal chromosomes?
    a. Diagram to demonstrate how daughter cells receive both maternal and paternal chromosomes.
6. What process occurs during meiosis I that causes daughter cells to be haploid?
7. What is nondisjunction?
    a. Describe how the resulting daughter cells differ depending on whether this occurs in meiosis I or meiosis II.
8. What checkpoint fails leading to nondisjunction?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.2.A: Explain how the process of meiosis generates genetic diversity.</td></tr>
<tr><td>5.2.A.2: During prophase I of meiosis, non-sister chromatids exchange genetic material via a process called crossing over (recombination), which increases genetic diversity among the resultant gametes.</td><td>☐ I can explain the process of crossing over.
☐ I can explain ways that crossing over increases genetic diversity.</td></tr>
</table>

9. What is crossing over?
10. How does crossing over increase genetic diversity?
11. TRUE OR FALSE: Crossing over occurs during mitosis AND meiosis.
12. TRUE OR FALSE: Crossing over in meiosis increases genetic diversity vs mitosis has no affect of genetic diversity.

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.2.A: Explain how the process of meiosis generates genetic diversity.</td></tr>
<tr><td>5.2.A.3: Sexual reproduction in eukaryotes increases genetic variation, including crossing over, random assortment of chromosomes during meiosis, and subsequent fertilization of gametes.
☒ Exclusion Statement: Knowledge of the details of sexual reproduction cycles in various plants and animals is beyond the scope of the AP Exam.</td><td>☐ I can describe ways that segregation, independent assortment, and fertilization lead to genetic variation.
☐ I can explain the process of independent assortment.
☐ I can explain ways that independent assortment increases genetic diversity.
☐ I can explain ways that random fertilization increases genetic diversity.</td></tr>
</table>

13. How does segregation lead to genetic variation?
14. What is independent assortment?
15. How does independent assortment increase genetic diversity?
16. What is random fertilization?
17. How does random fertilization increase genetic diversity?

AP Biology Exam Review

Topic 5.3: Mendelian Genetics

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</td></tr>
<tr><td colspan="2">5.3.A: Explain the inheritance of genes and traits as described by Mendel’s laws.</td></tr>
<tr><td>5.3.A.1: Mendel’s laws of segregation and independent assortment can be applied to genes that are on different chromosomes.</td><td>☐ I can explain the inheritance of genes and traits as described by Mendel’s laws.
☐ I can explain the law of segregation.
☐ I can explain the law of independent assortment.</td></tr>
</table>

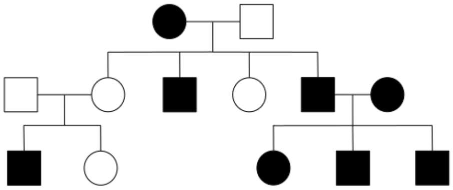
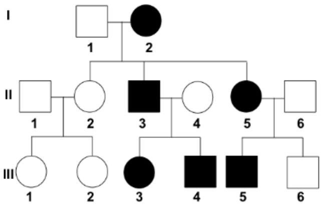
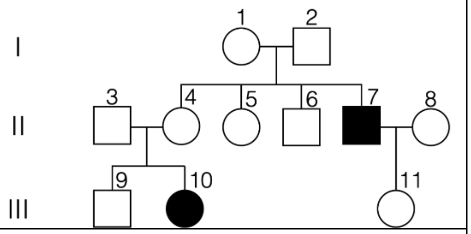
1. Identify Mendel’s laws.
2. Describe the law of segregation.
3. Describe the law of independent assortment.

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</td></tr>
<tr><td colspan="2">5.3.A: Explain the inheritance of genes and traits as described by Mendel’s laws.</td></tr>
<tr><td>5.3.A.2: In most cases, fertilization involves the fusion of two haploid gametes, restoring the diploid number of chromosomes and increasing genetic variation in populations by creating new combinations of alleles in the zygote.
i. Rules of probability can be applied to analyze the passing of single-gene traits from parent to offspring.
ii. Monohybrid, dihybrid, and test crosses can be used to determine whether alleles are dominant or recessive.
iii. An organism’s genotype is the set of alleles inherited for one or more genes by an individual organism. An organism’s genotype can be homozygous or heterozygous for each gene.
iv. An organism’s phenotype is the observable expression of the inherited traits.
v. Patterns of inheritance (autosomal, genetically linked, sex-linked) and whether an allele is dominant or recessive can often</td><td>☐ I can describe the function of fertilization.
☐ I can apply the rules of probability to analyze the passing of single-gene traits parent to offspring
☐ I can describe monohybrid crosses.
☐ I can identify the expected ratios of a monohybrid based on Mendel’s laws.
☐ I can describe dihybrid crosses.
☐ I can identify the expected ratios of a dihybrid based on Mendel’s laws.
☐ I can describe test crosses.
☐ I can identify the genotype vs the phenotype of an organism.
☐ I can identify the difference between homozygous vs heterozygous.
☐ I can describe the difference between autosomal, genetically linked, and sex-linked
☐ I can determine if an allele is dominant or recessive.
☐ I can apply evidence from a pedigree.
☐ I can apply evidence from a Punnett square.</td></tr>
</table>

be predicted from data, including pedigrees. Punnett squares can be used to predict the genotypes and phenotypes of parents and offspring. **Laws of Probability** If A and B are mutually exclusive, then: $P(\text{A or B}) = P(\text{A}) + P(\text{B})$ If A and B are independent, then: $P(\text{A and B}) = P(\text{A}) \times P(\text{B})$	

4. What is the function of fertilization?
    a. How does the ploidy of the gametes compare to the zygote?
    b. What is the difference in ploidy significant?
5. What is a monohybrid cross?
    a. Diagram a Punnett square for a monohybrid cross.
    b. What is the expected genotypic ratio of a monohybrid cross based on Mendel's laws?
    c. What is the expected phenotypic ratio of a monohybrid cross based on Mendel's laws?
6. What is a dihybrid cross?
    a. Diagram a Punnett square for a dihybrid cross (NOTE: I recommend TWO monohybrid crosses).
    b. What is the expected genotypic ratio of a dihybrid cross based on Mendel's laws? NOTE: Be sure to show ALL work
    c. What is the expected phenotypic ratio of a dihybrid cross based on Mendel's laws? NOTE: Be sure to show ALL work
7. What are the parent's genotype if the F1 ratio is 1:1?
8. What is complete dominance?
9. What is a test cross?
    a. Diagram a test cross to demonstrate the difference between a homozygous dominant vs a heterozygous unknown individual.
10. Describe the difference between a homozygous or heterozygous individual.
11. Describe the difference in an autosomal inheritance vs a linked trait inheritance.
12. What does it mean if an allele is dominant?
13. What does it mean if an allele is recessive?
14. How could a homozygous dominant and heterozygous individual have the same phenotype?
15. How do you determine if a trait is dominant or recessive?
16. What would you look for in a pedigree to identify if the trait is dominant or recessive?
17. What would you look for in a pedigree to identify if the trait is autosomal or sex-linked?

18. Determine the mode of inheritance of the following pedigrees and justify your inheritance determination:

Pedigree:		
	 I 1 2 II 1 2 3 4 5 6 III 1 2 3 4 5 6	 I 1 2 II 3 4 5 6 7 8 III 9 10 11
Mode of Inheritance & Justification		

Topic 5.4: Non-Mendelian Genetics

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.4.A: Explain deviations from Mendel's model of the inheritance of traits.</td></tr>
<tr><td>5.4.A.1: Patterns of inheritance of many traits do not follow the ratios predicted by Mendel's laws and can be identified by quantitative analysis, when the observed phenotypic ratios statistically differ from the predicted ratios.
i. Genes located on the same chromosome are referred to as being genetically linked. The probability that these linked genes segregate together during meiosis can be used to calculate the map distance (or map units) between them on a chromosome. This calculation is called gene or genetic mapping.
ii. Codominance occurs when the phenotype from both alleles is expressed such that the heterozygote would have a different phenotype than either homozygote.
iii. Incomplete dominance occurs when neither allele of a gene can mask the other, so the phenotype of the heterozygote is a blended version of the dominant and recessive phenotypes.</td><td>☐ I can explain deviations from Mendel's model of the inheritance of traits.
☐ I can explain linked genes.
☐ I can determine the distance between two genes on a chromosome.
☐ I can describe codominance.
☐ I can describe how predicted offspring from codominance differs from Mendelian predictions.
☐ I can describe incomplete dominance.
☐ I can describe how predicted offspring from incomplete dominance differs from Mendelian predictions.</td></tr>
</table>

1. What are linked traits?
    a. How are the predicted ratios different in linked genes?
    b. How would this be observed in a pedigree? (Note: go back to check your pedigree identifications in 5.2)
2. How do you calculate map units of two genes?
    a. Determine the map units between A, B, and C based on the following information:
       A – B: 13.2%, B – C = 6.4%, A – C = 18.5%
    b. Determine the map units between body color and wing shape based on the following information:
       Gray Body/Normal Wings = 1239, Black Body/Vestigial Wings = 1295
       Gray Body/Vestigial Wings = 156, Black Body/Normal Wings = 149
    c. If the recombination frequency is 15%, how far apart are the two genes?
3. What is codominance?
    a. Diagram a Punnett square for a monohybrid cross with codominance.
    b. What is the expected genotypic ratio of this cross?

   c. What is the expected phenotypic ratio of this cross?

4. What is incomplete dominance?
   a. Diagram a Punnett square for a monohybrid cross with incomplete dominance.
   b. What is the expected genotypic ratio of this cross?
   c. What is the expected phenotypic ratio of this cross?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">5.4.A: Explain deviations from Mendel's model of the inheritance of traits.</td></tr>
<tr><td>5.4.A.2: Some traits, known as sex-linked traits (X- or Y-linked), are determined by genes on sex chromosomes. The pattern of inheritance of sex-linked traits can often be predicted from data, including pedigrees, indicating the genotypes and phenotypes of both parents and offspring.</td><td>☐ I can describe sex-linked traits.
☐ I can predict the inheritance of a sex-linked trait based on a pedigree.
☐ I can predict inheritance of a sex-linked trait based on data indicating parental genotypes.
☐ I can predict inheritance of a sex-linked trait based on data indicating parental phenotypes.
☐ I can predict inheritance of a sex-linked trait based on data indicating offspring genotypes.
☐ I can predict inheritance of a sex-linked trait based on data indicating offspring phenotypes.</td></tr>
</table>

5. What are sex-linked traits?
6. TRUE OR FALSE: Sex-linked traits only affect the X chromosome.
7. TRUE OR FALSE: Sex-linked traits affect males more frequently than females.
8. If a male is affected with a sex-linked trait with unaffected parents, what are the genotypes of the parents?
9. What type of sex-linked cross would result in a 2 normal females, 1 normal male, and 1 affected male?
10. If given a pedigree, how would you determine if the trait is sex-linked?
11. Practice a few sex-linked Punnett squares:
    a. An affected female with a recessive X-linked trait and an unaffected male
    b. An affected male with a recessive X-linked trait and an unaffected female
    c. A carrier female with a recessive X-linked trait and an affected male.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
5.4.A: Explain deviations from Mendel's model of the inheritance of traits.	
5.4.A.3: Pleiotropy is a phenomenon in which the expression of a single gene results in multiple traits or effects; these traits therefore do not segregate independently.	☐ I can describe pleiotropy.

12. What is pleiotropy?
    a. Provide ONE example of pleiotropy.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
5.4.A: Explain deviations from Mendel's model of the inheritance of traits.	
5.4.A.4: Some traits result from non-nuclear inheritance. i. Chloroplasts and mitochondria are randomly assorted to gametes and daughter cells; thus, traits determined by chloroplast and mitochondrial DNA do not follow simple Mendelian rules. ii. In animals, mitochondria are usually transmitted by the egg and not by sperm; thus, traits determined by the mitochondrial DNA are typically maternally inherited. iii. In plants, mitochondria and chloroplasts are transmitted in the ovule and not in the pollen; as such, mitochondria-determined and chloroplast-determined traits are typically maternally inherited.	☐ I can identify organelles other than the nucleus that contain DNA. ☐ I can determine which gamete mitochondria are transmitted by. ☐ I can determine inheritance of a mitochondrial linked trait based on a pedigree. ☐ I can determine which gamete chloroplasts are transmitted by. ☐ I can determine inheritance of a chloroplast linked trait based on a pedigree.

13. What organelles contain DNA?
    a. How does this support the endosymbiotic theory?
14. If a trait is mitochondrially linked, what is the mode of inheritance?
    a. If an animal or plant has a mitochondrial linked trait, which gamete is responsible for this inheritance?
15. If a trait is found on the DNA in a chloroplast, what is the mode of inheritance?
    a. If a plant has a chloroplast linked trait, which gamete is responsible for this inheritance?
16. What would you look for in a pedigree to identify if the trait is due to non-nuclear inheritance?

Topic 5.5: Environmental Effects of Phenotype

<table>
<tr><td colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</td></tr>
<tr><td colspan="2">5.5.A Explain how the same genotype can result in multiple phenotypes under different environmental conditions.</td></tr>
<tr><td>5.5.A.1: Environmental conditions influence gene expression and can lead to phenotypic plasticity (e.g., the ability of individual genotypes to produce different phenotypes).</td><td>☐ I can explain ways the same genotype can result in multiple phenotypes under different environmental conditions.
☐ I can describe phenotype plasticity.
☐ I can provide examples of phenotype plasticity.
☐ I can describe ways environmental factors influence gene expression.</td></tr>
</table>

1. What is phenotype plasticity?
    a. Identify two examples of phenotype plasticity,
    b. What is the evolutionary significance of phenotype plasticity?
2. How do environmental factors affect gene expression?

Multiple Choice Practice

1. Humans have a diploid number ("2n") of 46. Which of the following statements best predicts the consequence if meiosis did not occur during gametogenesis?
    a. The gametes would get larger from one generation to the next.
    b. The chromosome number would double with each generation.
    c. The chromosome number would be halved with each generation.
    d. The chromosome number would triple with each generation.

Use the following information to answer question 2:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

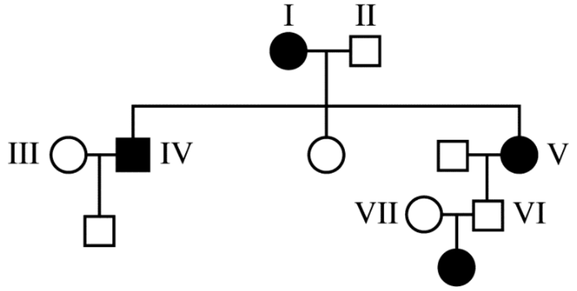
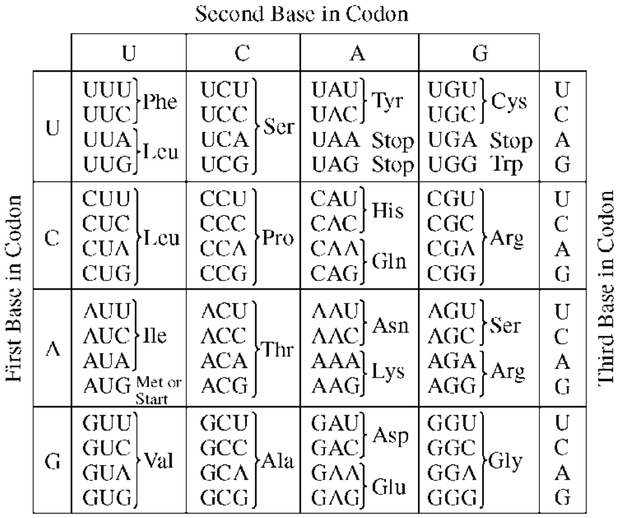


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3'	Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5'	Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.



	Second Base in Codon				
First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU UUC} Phe UUA UUG} Leu	UCU UCC UCA UCG} Ser	UAU UAC} Tyr UAA Stop UAG Stop	UGU UGC} Cys UGA Stop UGG Trp	U C A G
C	CUU CUC CUA CUG} Leu	CCU CCC CCA CCG} Pro	CAU CAC} His CAA CAG} Gln	CGU CGC CGA CGG} Arg	U C A G
A	AUU AUC AUA} Ile AUG Met or Start	ACU ACC ACA ACG} Thr	AAU AAC} Asn AAA AAG} Lys	AGU AGC} Ser AGA AGG} Arg	U C A G
G	GUU GUC GUA GUG} Val	GCU GCC GCA GCG} Ala	GAU GAC} Asp GAA GAG} Glu	GGU GGC GGA GGG} Gly	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

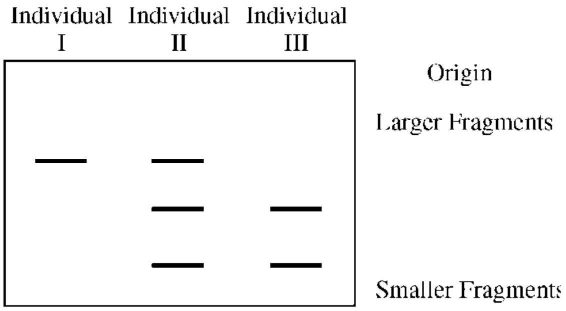


Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

2. Based on the data shown in Figure 1, which of the following best describes the genotypes of individual family members in the pedigree?
    a. All affected individuals possess at least one dominant allele of the hemoglobin beta gene.
    b. Healthy individuals may possess one mutant allele (HbS) of the hemoglobin beta gene.
    c. Individuals IV and V must be heterozygous for the HbS (mutant) allele.
    d. Individuals II and VI possess two copies of the HbA (wild-type) allele.

3. The tiny blue-eyed Mary flower is often one of the first flowers seen in the spring in some regions of the United States. The flower is normally blue, but sometimes a white or pink flower variation is found. The following data were obtained after several crosses.

Parents	F_1	F_2
Blue x White	Blue	196 Blue, 63 White
Blue x Pink	Blue	149 Blue, 52 Pink
Pink x White	Blue	226 Blue, 98 White, 77 Pink

Which of the following statements best explains the data?
    a. The appearance of blue in the F1 generation of the pink and white cross demonstrates that flower color is not an inherited trait but is determined by the environment.
    b. Flower color depends on stages of flower development, and young flowers are white, advancing to pink and then blue.
    c. Since the F1 and F2 phenotypes of the pink and white cross do not fit the expected genotypic and phenotypic ratios, blue-eyed Mary must reproduce by vegetative propagation.
    d. Flower color is an inherited trait, and the F1 and F2 phenotypes of the flowers arising from the pink and white cross can best be explained by another gene product that influences the phenotypic expression.

4. A student in a biology class crossed a male Drosophila melanogaster having a gray body and long wings with a female D. melanogaster having a black body and apterous wings. The following distribution of traits was observed in the offspring.

Phenotype	Number of Offspring
Gray body, long wings	42
Black body, apterous wings	41
Gray body, apterous wings	9
Black body, long wings	8

Which of the following is supported by the data?
    a. The alleles for gray body and long wings are dominant.
    b. The alleles for gray body and long wings are recessive.
    c. Genes for the two traits are located on two different chromosomes, and independent assortment occurred.
    d. Genes for the two traits are located close together on the same chromosome and crossing over occurred between the two gene loci.

Use the following information for question 5:

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.

	Dish A		**Dish B**	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

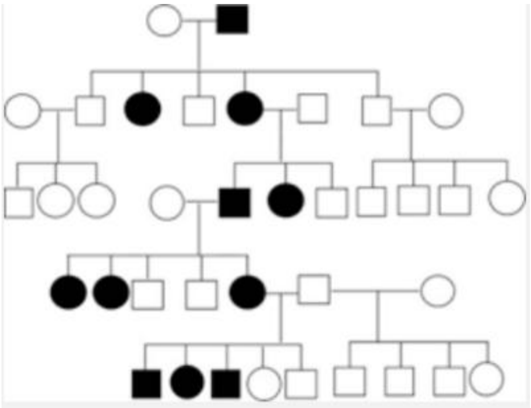
5. Which of the following best supports the hypothesis that the difference in leaf color is genetically controlled?
   a. The number of yellow-leaved seedlings in dish A on day 7
   b. The number of germinated seeds in dish A on days 7 and 14
   c. The death of all the yellow-leaved seedlings
   d. The existence of yellow-leaved seedlings as well as green-leaved ones on day 14 in dish B

6. Mitosis results in...
   a. 2 identical diploid cells
   b. 4 unique diploid cells
   c. 2 unique haploid cells
   d. 4 identical haploid cells

7. Meiosis results in _____________ because there is/are _______________.
   a. 2 identical haploid cells, 1 round of division
   b. 4 identical diploid cells, 2 rounds of division
   c. 4 unique haploid cells, 2 rounds of division
   d. 2 unique diploid cells, 1 round of division

8. Which of the following does NOT increase variation in gamete formation?
   a. crossing over
   b. fertilization of gametes
   c. random assortment of chromosomes
   d. condensation of chromatin

9. This process involves homologous chromatids exchanging genetic material to increase genetic diversity.
   a. crossing over
   b. random fertilization
   c. independent assortment
   d. gene flow



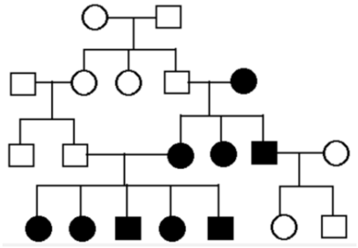
10. Which of the following best describes the inheritance pattern of the shown pedigree?
    a. Autosomal Dominant
    b. Sex-Linked Dominant
    c. Autosomal Recessive
    d. Sex-Linked Recessive

11. Which of the following best describes the phenotypic ratio of 6:3:3:2:1:1?
    a. Incomplete dominance & complete dominance on dihybrid cross
    b. Incomplete dominance on dihybrid cross
    c. Complete dominance on dihybrid cross
    d. Epistasis on dihybrid cross

12. Describe the cause of a cross resulting in greater than 50% parental phenotypes and less then 50% recombinant phenotypes
    a. Genes are linked on the same chromosome
    b. Genes are located on different arms of the same chromosome
    c. Gene are on different chromosomes
    d. Gene are found in different gametes

13. In animals, traits determine by the mitochondrial DNA are inherited from the _______________.
    a. mother
    b. brother
    c. father
    d. sister

14. Identify the type of inheritance of the pedigree.
    a. Sex-Linked
    b. Mitochondrial
    c. Autosomal
    d. Random



15. Snowshoe hares are brown in summer and white in winter, describe this event.
    a. Hares undergo phenotypic plasticity & environment influences gene express
    b. Hares are white in winter due to the snow binding to hair follicles
    c. Hares are brown from exposed dirt in summer
    d. Hares remain hidden in the winter months inhibiting fur darken from sun

16. Describe the process of nondisjunction.
    a. Homologous chromosomes exchange genetic information
    b. The alignment of the chromosomes on the metaphase plate
    c. Homologous chromosomes or sister chromatids remain attached during anaphase
    d. The process of sperm and egg fusing to create a zygote

17. When does the process of independent assortment take place?
    a. prophase I
    b. metaphase I
    c. anaphase I
    d. telophase I

18. When does the process of crossing over take place?
    a. prophase I
    b. metaphase I
    c. anaphase I
    d. telophase I

19. What phase of meiosis describes the law of segregation?
    a. telophase I
    b. anaphase I
    c. telophase II
    d. anaphase II

20. Which of the following is the predicted ratio of a testcross with a dihybrid?
    a. 9:3:3:1
    b. 9:6:1
    c. 1:2:1
    d. 1:1:1:1

21. Which of the following is a predicted ratio of a dihybrid cross?
    a. 9:3:3:1
    b. 9:3:4
    c. 1:2:1
    d. 1:1:1:1

22. Describe why a male is more likely to be affected by a sex-linked trait?
    a. Males have only 1 Y chromosome
    b. Females have only 1 Y chromosome
    c. Males have only 1 X chromosome
    d. Females have only 1 X chromosomes

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	B. The chromosome number would double with each generation.	5.1	2020 CED #2
2	B. Healthy individuals may possess one mutant allele (HbS) of the hemoglobin beta gene.	5.3*	2013 #48
3	D. Flower color is an inherited trait, and the F1 and F2 phenotypes of the flowers arising from the pink and white cross can best be explained by another gene product that influences the phenotypic expression.	5.4	2012 CED #32
4	D. Genes for the two traits are located close together on the same chromosome and crossing over occurred between the two gene loci.	5.4	2013 #33
5	D. The existence of yellow-leaved seedlings as well as green-leaved ones on day 14 in dish B	5.5	2012 CED #8
6	A. 2 identical diploid cells	5.1	Self
7	C. 4 unique haploid cells, 2 rounds of division	5.1	Self
8	D. condensation of chromatin	5.2	Self
9	A. crossing over	5.2	Self
10	A. Autosomal Dominant	5.3	Self
11	A. Incomplete dominance & complete dominance on dihybrid cross	5.3	Self
12	A. Genes are linked on the same chromosome	5.4	Self
13	A. mother	5.4	Self
14	B. Mitochondrial	5.4	Self
15	A. Hares undergo phenotypic plasticity & environment influences gene express	5.5	Self
16	C. Homologous chromosomes or sister chromatids remain attached during anaphase	5.2	Self
17	B. metaphase I	5.1	Self
18	A. prophase I	5.1	Self
19	B. anaphase I	5.1	Self
20	D. 1:1:1:1	5.3	Self
21	A. 9:3:3:1	5.3	Self
22	C. Males have only 1 X chromosome	5.3	Self

Multiple Choice Explanations

Q		Explanation:
1	A	Gametes arise from germ cells within the gonads. These cells do not undergo serial divisions. The cells would not increase in size with each generation.
	B	**The function of meiosis is to create a cell with half of the chromosome number (gamete). By having half of the chromosome number, the organism will get a full set after the fusion of two gametes. If meiosis did not occur, there would be 2n in each of the cells. When these two cells fuse, there would be 4n which is double the original chromosome number. If meiosis again did not occur, there would be 4n in each of the cells. When these two cells fuse, there would be 8n which is double the previous generation.**
	C	The function of meiosis is to create a cell with half of the chromosome number. If meiosis does not occur, the chromosome number would not be reduced. This answer choice is describing what would happen if there was no fusion of gametes but the cell underwent meiosis each generation.
	D	The function of meiosis is to create a cell with half of the chromosome number (gamete). This answer choice describes a triple with each generation which is not possible as there are two sets of chromosomes.
2	A	Based on the offspring between individual VII and VI, it can be determined that sickle cell disease is an autosomal recessive trait. An affected individual would have two of the HbS alleles which is recessive.
	B	**Based on the pedigree, Individual II and III are unaffected while individual I is affected. Based on the offspring between individual VII and VI, it can be determined that sickle cell disease is an autosomal recessive trait. Based on the gel electrophoresis, it can be determined that individual I is HbS HbS, individual II is HbS HbA, and individual III is HbA HbA. Since individual II is unaffected, we can state that healthy individuals may posses one mutant allele.**
	C	Based on the pedigree, both individuals IV and V are affected and have two HbS alleles, so they are not heterozygous.
	D	Based on the pedigree, both individuals II and VI are heterozygous (both have an affected offspring), so they do not have two copies of the HbA allele.
3	A	If it was caused by the environment, there would not be the "sometimes a white or pink flower variation is found" because the flowers are all in the same environment. This option is incorrect because if the environment determined the flower color, then the occasional white and pink flower would not be seen in the original environment. (CollegeBoard)
	B	The prompt gives no information about the flowers being observed at different times. Logically, all of the flowers in a generation would be observed and recorded at the same time. This option is incorrect because there is no indication of the stages of flower development, and the 3:1 ratios in the first two crosses would not be seen if the stage of flower development were the controlling factor. (CollegeBoard)
	C	Vegetative propagation is asexual reproduction. These ratios are appropriate ratios of a 3:1 of blue to white or blue to pink and 1:2:1 of white to blue to pink. This option is incorrect because the crosses of blue and white and blue and pink do fit expected phenotypic ratios. Vegetative propagation would not result in the ratios indicated by the data. (CollegeBoard)

	D	**In the first cross, if you assume true-breeding parents, it is logical to get a heterozygous blue in F1 and a 3:1 ratio of blue to white in F2 generation. In the second cross, if you assume true-breeding parents, it is logical to get a heterozygous blue in F1 and a 3:1 ratio of blue to pink in F2 generation. In the third cross, the pink and white cross leads to blue in F1 and a 1:2:1 ratio of white to blue to pink in F2 generation similar to incomplete dominance or another gene product the influences expression.** **This option is correct. The student is asked to evaluate the data given. The crosses between blue / white and blue / pink show expected 3:1 ratios in the F1 generation. The appearance of a majority of blue flowers in the F1 cross between pink and white indicate that there is another gene product affecting the outcome. (CollegeBoard)**
4	A	If the allele for gray and long were dominant, then you would expect to find most offspring to be gray/long.
	B	If the allele for gray and long were recessive, then you would expect to find less offspring to be gray/long as they could be masked by the other phenotype.
	C	If you were to observe independent assortment, then you would find that there would be a 1:1:1:1 ratio which is not observed in the data. There would be an equal number of each of the phenotypes.
	D	**You would expect to find a 1:1:1:1 ratio if the gray/long was heterozygous. Since you find most of the individuals look like the parentals this shows you that the two genes must be close together on one chromosome. The recombinants come from crossing over.**
5	A	Dish A was not exposed to light, so the yellow leaves could be a result of the absence of light. This option is incorrect because the leaves in dish A could have been yellow because they had not been exposed to light yet and could have changed to green in response to light, which would not be a genetic difference. Some yellow leaves did change to green when exposed to light. (CollegeBoard)
	B	The seed germination was a result of exposure to light. The germination is not genetically controlled and is based on the environment. This option is incorrect because the only variable in this experiment was light. If genes responsible for leaf color also had an impact on germination rate, then germination should have been similar in each dish, which is not supported. (CollegeBoard)
	C	All of the yellow-leaved seedlings did not die. There are 6 found on day 14 in Dish A and 5 found on day 14 in Dish B. This option is incorrect because according to the data, no seedlings died. (CollegeBoard)
	D	**Dish B was never covered but there are green and yellow leaved seedlings.** **This option is correct because both colors of leaves existed after 14 days and essentially in the same numbers. If the green color resulted from a response to light, then the yellow leaves would have changed to green by 14 days. (CollegeBoard)**
6	A	**Mitosis is a form of asexual reproduction and makes identical cells to the parent. In the process of division, one cell will split into two. The result is TWO identical DIPLOID cells.**
	B	Each round of division will produce 2 cells, so in order to have four cells – there needs to be two rounds of division. Mitosis only has 1 round of division. In addition, the result of mitosis are identical cells.
	C	Mitosis produces identical cells.
	D	Mitosis has only 1 round of division which only makes 2 cells.

7	A	Meiosis has two rounds of divisions which results in four haploid cells.
	B	Meiosis has two rounds of divisions which results in four haploid cells.
	C	**Meiosis has two rounds of division with one round of DNA replication which produces 4 cells with half of the genetic information (haploid). Due to crossing over, the cells are genetically distinct.**
	D	Meiosis has two rounds of divisions which results in four haploid cells.
8	A	Sexual reproduction in eukaryotes involving gamete formation—including crossing over, the random assortment of chromosomes during meiosis, and subsequent fertilization of gametes—serves to increase variation. (ST-1.H.3)
	B	Sexual reproduction in eukaryotes involving gamete formation—including crossing over, the random assortment of chromosomes during meiosis, and subsequent fertilization of gametes—serves to increase variation. (ST-1.H.3)
	C	Sexual reproduction in eukaryotes involving gamete formation—including crossing over, the random assortment of chromosomes during meiosis, and subsequent fertilization of gametes—serves to increase variation. (ST-1.H.3)
	D	**Condensation of chromatin will ensure that the genetic material is equally distributed to each cell and does not increase variation as this is just condensing the genetic material that already exists.**
9	A	**During meiosis I, homologous chromatids exchange genetic material via a process called "crossing over" (recombination), which increases genetic diversity among the resultant gametes.** (IST-1.H.2)
	B	Random fertilization states that it is random which sperm and egg fuse during fertilization.
	C	Independent assortment refers to the independence of homologous pairs to align on the metaphase plate. It is random which pair align to which pole of the cell.
	D	Gene flow refers to the movement of alleles in and out of a population. This is immigration and emigration which results in allele movement between populations.
10	A	**The mode of inheritance is autosomal dominant. You can tell it is dominant from two observations. Unaffected parents do not have an affected offspring. There is an affected individual in each generation. Autosomal is demonstrated by males and females being equally likely to be affected.**
	B	The mode of inheritance is autosomal dominant. You can tell it is dominant from two observations. Unaffected parents do not have an affected offspring. There is an affected individual in each generation. To be completely honest, I am having trouble arguing about this not being sex-linked. Following the X should be more obvious, an affected father and unaffected mother having an unaffected daughter would show it is not sex-linked. I admit defeat and you could argue this is a correct answer.
	C	Unaffected parents do not have an affected offspring demonstrating this is dominance.
	D	If this was sex-linked recessive, the affected female would be unable to have an unaffected male. Both of the Xs in the female are affected and the male would only have one X so he should be affected.
11	A	**Incomplete dominance gives a 1:2:1 ratio while complete dominance gives a 3:1 ratio. If you multiply these together → !:2:1 x 3:1 = 3:6:3:1:2:1 which rearranged is 6:3:3:2:1:1**
	B	Incomplete dominance gives a 1:2:1 ratio. If both are incomplete dominance, you would get → 1:2:1 x 1:2:1 = 1:2:1:2:4:2:1:2:1 which rearranged is 4:2:2:2:2:1:1:1:1
	C	Complete dominance gives a 3:1. If both complete dominance, you would get → 3:1 x 3:1 = 9:3:3:1
	D	Epistasis leads to one gene masking another so it would be 9:3:4 or 12:3:1 or 9:6:1 which combines two of the ratios from 9:3:3:1.
12	A	**(a) Genes that are adjacent and close to one another on the same chromosome may appear to be genetically linked; the probability that genetically linked genes will segregate as a unit can be used to calculate the map distance between them. (IST-1.J.1). This will result in greater than 50% parentals and less than 50% recombinants.**

	B	If it was located on different arms, the two genes would be located far apart so it would demonstrate independent assortment.
	C	If it was found on different chromosomes, then the alleles will be inherited independently and demonstrate independent assortment.
	D	This doesn't make sense. This is saying that one gamete has a gene for flower color and the other gamete has a gene for pod shape. The gamete has different alleles for each of these in ALL of the cells.
13	A	**Some traits result from non-nuclear inheritance—(b) In animals, mitochondria are transmitted by the egg and not by sperm; as such, traits determined by the mitochondrial DNA are maternally inherited (IST-1.J.4)**
	B	Mitochondria is inherited from gametes, specifically the egg. The brother does not contribute mitochondria.
	C	Mitochondria is inherited from gametes, specifically the egg. The father does not contribute mitochondria.
	D	Mitochondria is inherited from gametes, specifically the egg. The sister does not contribute mitochondria.
14	A	Not sex-linked since the affected father has an unaffected daughter.
	B	**This demonstrates mitochondrial inheritance as an affected mother has ALL affected offspring and an unaffected mother has NO affected offspring.**
	C	Not autosomal because there would be a 3% chance of getting 5 affected offspring in the last cross. The exam will have obvious pedigrees. The pedigree is obvious to show the affected mother and all affected children to push you to mitochondrial.
	D	A random inheritance would not lead to that many affected individuals, especially since it is random.
15	A	**Environmental factors influence gene expression and can lead to phenotypic plasticity. Phenotypic plasticity occurs when individuals with the same genotype exhibit different phenotypes in different environments. (SYI-3.B.1)**
	B	The snow would not cover the entire hare, plus this would inhibit movement of the hare and decrease its body temperature which would be a disadvantage.
	C	The dirt would not cover the entire hare.
	D	Fur does not work like the melanin in our skin.
16	A	Crossing over is when homologous chromosomes exchange genetic information
	B	The alignment of the chromosomes on the metaphase plate describes the process that occurs during metaphase
	C	**Nondisjunction occurs when the homologous pairs do not segregate during anaphase I or the sister chromatids do not segregate in anaphase II. This causes a chromosomal mutation leading to an additional chromosome or absence of a chromosome in a cell.**
	D	Fertilization is when sperm and egg fuse to create a zygote
17	A	Crossing over takes place in prophase I.
	B	**Homologous chromosomes align independently on the metaphase plate during metaphase I.**
	C	Homologous chromosomes segregate to opposite poles during anaphase I.
	D	Telophase I results in 2 haploid cells with 2 sister chromatids.
18	A	**Crossing over takes place in prophase I.**
	B	Homologous chromosomes align independently on the metaphase plate during metaphase I.
	C	Homologous chromosomes segregate to opposite poles during anaphase I.
	D	Telophase I results in 2 haploid cells with 2 sister chromatids.
	A	Telophase I results in 2 haploid cells with 2 sister chromatids AFTER the homologous chromosomes have segregated.

19	B	**Homologous chromosomes segregate to opposite poles during anaphase I which results in segregation of alleles (law of segregation).**
	C	Telophase II results in 4 haploid cells with 1 chromatids AFTER the sister chromatids have segregated.
	D	Sister chromatids segregate to opposite poles during anaphase II.
20	A	9:3:3:1 describes the phenotypic result of a dihybrid cross (both parents are heterozygous for two traits)
	B	9:6:1 describes the phenotypic result of a dihybrid cross (both parents are heterozygous for two traits) and epistasis.
	C	1:2:1 describes the phenotypic result of a monohybrid cross (both parents are heterozygous for one trait) and incomplete dominance or codominance.
	D	**A testcross is crossed with a homozygous recessive. 1:1:1:1 describes the phenotypic result of a dihybrid with a homozygous recessive for both alleles individual.**
21	A	**9:3:3:1 describes the phenotypic result of a dihybrid cross (both parents are heterozygous for two traits)**
	B	9:6:1 describes the phenotypic result of a dihybrid cross (both parents are heterozygous for two traits) and epistasis.
	C	1:2:1 describes the phenotypic result of a monohybrid cross (both parents are heterozygous for one trait) and incomplete dominance or codominance.
	D	1:1:1:1 describes the phenotypic result of a dihybrid with a homozygous recessive for both alleles individual.
22	A	A Y-linked trait would ONLY affect males. Traditionally sex-linked traits are on the X chromosome and this answer choice does not refer to the X chromosomes.
	B	Females assigned at birth do not have a Y chromosome. The genotype of a female is XX.
	C	**Sex-linked traits are traditionally on an X chromosome. Males assigned at birth have a genotype of XY, so they only have one X chromosome. If the inherited X is affected, the individual will be affected. Unlike in a female assigned at birth has a genotype of XX which allows for an unaffected X to mask an affected X.**
	D	Females assigned at birth have a genotype of XX, so they have 2 X chromosomes.

Free Response Practice

2024 #1

Crossing over in meiosis I is required for homologous chromosomes to properly align during metaphase and segregate during the first cell division.

a)

i. **Describe** the function of S phase of interphase.

Some regions of a chromosome called hotspots display a higher frequency of crossing over than other regions do. Crossing over is suppressed in chromosomal regions near the centromeres. The centromere region of a duplicated chromosome includes a collection of proteins that form a structure called the kinetochore. Scientists hypothesized that one or more of these kinetochore proteins are responsible for suppressing crossing over around the centromere.
To investigate their hypothesis, scientists modified chromosome 8 in yeast such that, in each cell, one chromosome from the pair of homologous chromosome 8s contained the gene encoding red fluorescent protein (RFP), while the other chromosome from the pair contained the gene encoding green fluorescent protein (GFP). Cells expressing RFP emit (give off) red light, and cells expressing GFP emit green light. Models of the modified chromosome 8 both before and after crossing over are shown in Figure 1. Figure 1.

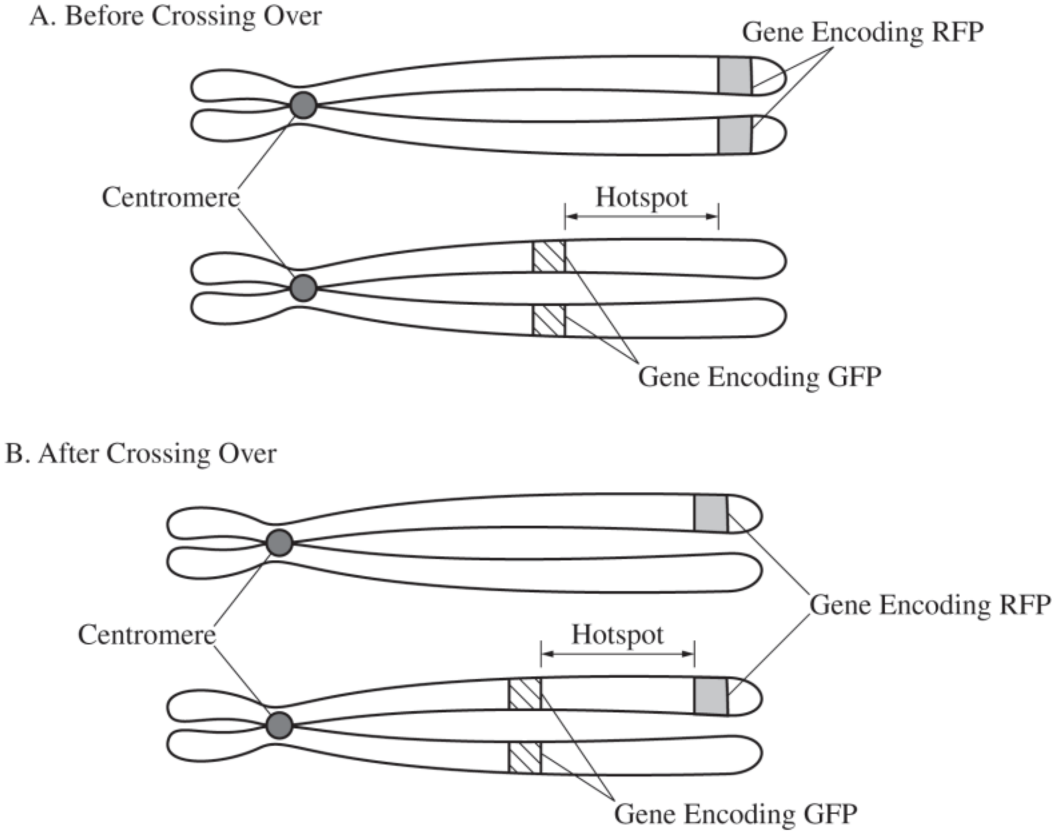

A. Before Crossing Over
Gene Encoding RFP
Centromere
Hotspot
Gene Encoding GFP
B. After Crossing Over
Centromere
Gene Encoding RFP
Hotspot
Gene Encoding GFP

Figure 1. Models of modified chromosome 8 used in the experiment (A) before and (B) after crossing over occurs at the hotspot

ii. **Explain** why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker

The scientists then investigated whether attaching individual kinetochore proteins to a specific DNA sequence present in a known crossing-over hotspot on chromosome 8 affected the frequency of crossing over at this location. In their first experiment, they examined three groups of yeast cells containing the modified chromosome 8. Group 1 contained no kinetochore proteins attached to the hotspot, group 2 contained the kinetochore protein CTF attached to the hotspot, and group 3 contained the kinetochore protein IML attached to the hotspot. For each group, the scientists determined the frequency of crossing over between the RFP and GFP genes. To determine the frequency, the scientists added the number of cells emitting both red and green light to the number of cells that emitted no light and divided by the total number of cells (Figure 2).

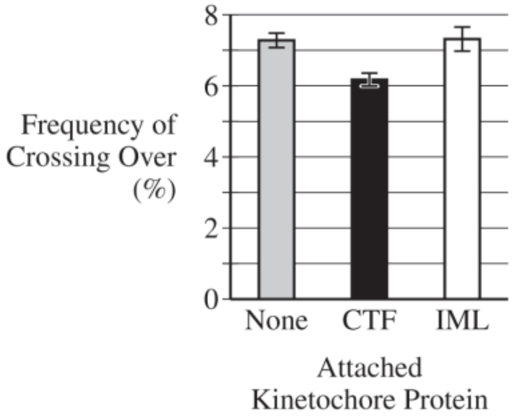


Figure 2. The frequency of crossing over in a hotspot on yeast chromosome 8 for cell groups treated with different kinetochore proteins. Error bars represent $\pm 2SE_{\bar{x}}$.

b)

i. **Identify** the control group for the scientists' first experiment, shown in Figure 2.

ii. In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control.

iii. **Identify** the independent variable in the follow-up experiment.

c) Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot.

d)

i. **Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot.

ii. Provide reasoning to **justify** your prediction.

iii. **Explain** how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures.

2023 #2

Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).

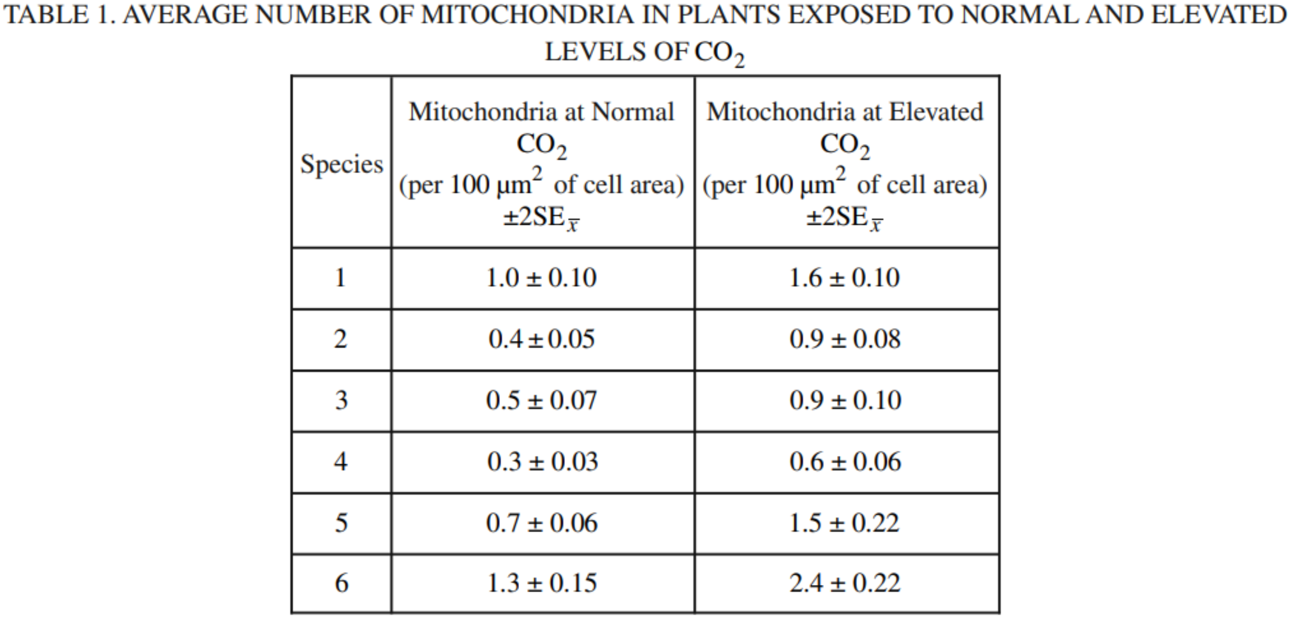


TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO_2

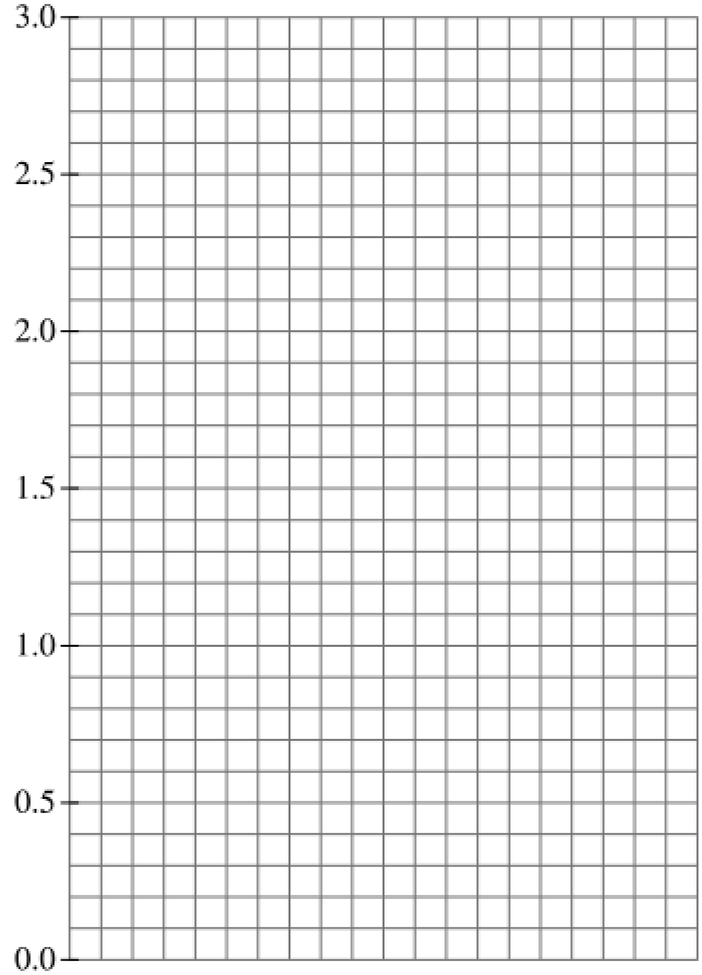
Species	Mitochondria at Normal CO_2 (per 100 μm^2 of cell area) ±2SE$_{\bar{x}}$	Mitochondria at Elevated CO_2 (per 100 μm^2 of cell area) ±2SE$_{\bar{x}}$
1	1.0 ± 0.10	1.6 ± 0.10
2	0.4 ± 0.05	0.9 ± 0.08
3	0.5 ± 0.07	0.9 ± 0.10
4	0.3 ± 0.03	0.6 ± 0.06
5	0.7 ± 0.06	1.5 ± 0.22
6	1.3 ± 0.15	2.4 ± 0.22

(a) **Describe** the role of the inner mitochondrial membrane in cellular respiration.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2.

(c) Based on the data in Table 1, **describe** the relationship between the level of CO_2 and the average number of mitochondria per unit area of a cell.

(d) The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. Provide reasoning to **justify** your prediction. **Explain** why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO_2.



2022 #2

During meiosis, double-strand breaks occur in chromatids. The breaks are either repaired by the exchange of genetic material between homologous non-sister chromatids, which is the process known as crossing over (Figure 1A), or they are simply repaired without any crossing over (Figure 1B). Plant breeders developing new varieties of corn are interested in determining whether, in corn, a correlation exists between the number of meiotic double-strand chromatid breaks and the number of crossovers.

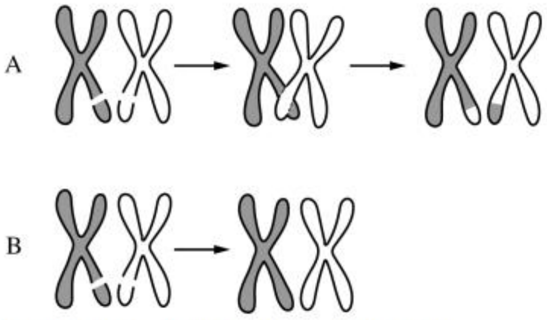


Figure 1. Double-strand breaks in chromatids are repaired with crossing over (A) or without crossing over (B).

Using specialized staining and microscopy techniques, scientists counted the number of double-strand chromatid breaks and the number of crossovers in the same number of meiotic gamete-forming cells of six inbred strains of corn (Table 1).

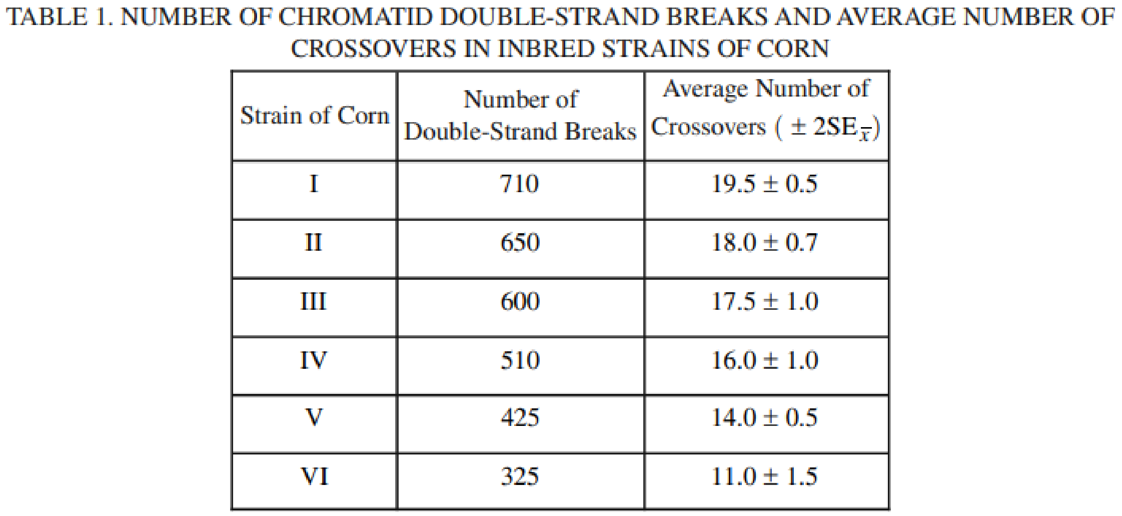


TABLE 1. NUMBER OF CHROMATID DOUBLE-STRAND BREAKS AND AVERAGE NUMBER OF CROSSOVERS IN INBRED STRAINS OF CORN

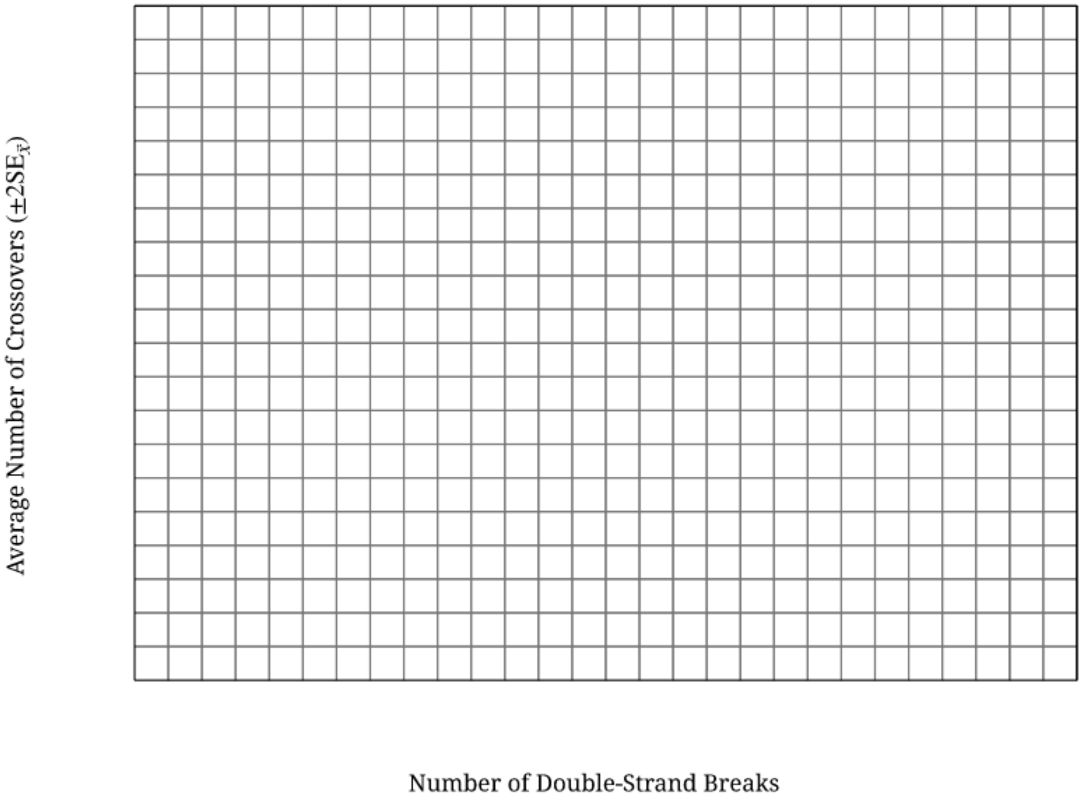
Strain of Corn	Number of Double-Strand Breaks	Average Number of Crossovers ($\pm 2SE_{\bar{x}}$)
I	710	19.5 ± 0.5
II	650	18.0 ± 0.7
III	600	17.5 ± 1.0
IV	510	16.0 ± 1.0
V	425	14.0 ± 0.5
VI	325	11.0 ± 1.5

(a) The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. Based on the data, determine whether corn strains I, II, and III differ in their average number of crossovers.

(c) Based on the data, **describe** the relationship between the average number of double-strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment.

(d) Crossing over (Figure 1A) creates physical connections that are required for proper separation of homologous chromosomes during meiosis. A diploid cell with four pairs of homologous chromosomes undergoes meiosis to produce four haploid cells. Crossing over occurs between only three of the pairs. **Predict** the number of chromosomes most likely present in each of the four haploid cells. Provide reasoning to **justify** your prediction. Explain how plant breeders can use the information in Table 1 to help develop new varieties of corn.



2021 #2

This question is in Unit 6.

2019 #3

The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.

(a) **Identify** the cellular location where PDC is most active.

(b) **Make a claim** about how PDC deficiency affects the amount of NADH produced by glycolysis AND the amount of NADH produced by the Krebs (citric acid) cycle in a cell. **Provide reasoning** to support your claims based on the position of the PDC-catalyzed reaction in the sequence of the cellular respiration pathway.

(c) PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

2019 #6

This question is in Unit 6.

2018 #1

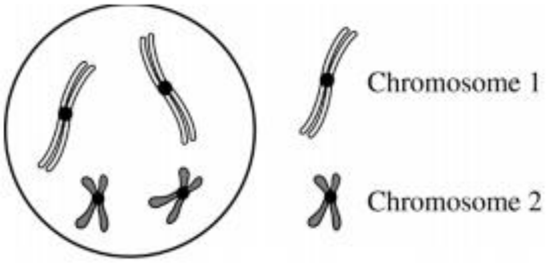
This question is in Unit 7.

2018 #8

This question is in Unit 8.

2016 #7

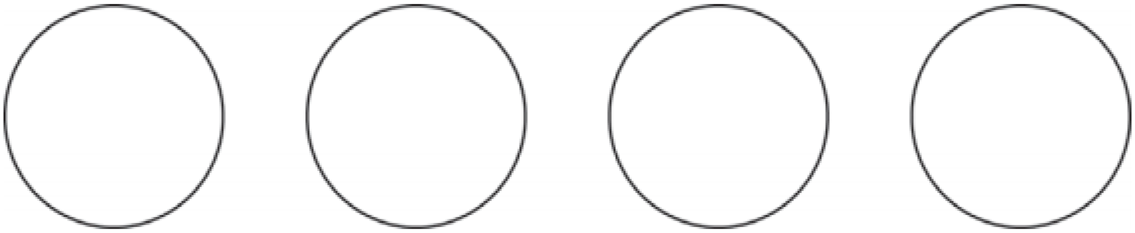
In a certain species of plant, the diploid number of chromosomes is 4 (2n = 4). Flower color is controlled by a single gene in which the green allele (G) is dominant to the purple allele (g). Plant height is controlled by a different gene in which the dwarf allele (D) is dominant to the tall allele (d). Individuals of the parental (P) generation with the genotypes GGDD and ggdd were crossed to produce F_1 progeny.



(a) **Construct** a diagram below to depict the four possible normal products of meiosis that would be produced by the F_1 progeny. Show the chromosomes and the allele(s) they carry. Assume the genes are located on different chromosomes and the gene for flow color is on chromosome 1.

(b) **Predict** the possible phenotypes and their ratios in the offspring of a testcross between an F_1 individual and a ggdd individual.

(c) If the two genes were genetically linked, **describe** how the proportions of phenotypes of the resulting offspring would most likely differ from those of the testcross between an F_1 individual and a ggdd individual.



2015 #4

Both mitosis and meiosis are forms of cell division that produce daughter cells containing genetic information from the parent cell.

(a) **Describe** TWO events that are common to both mitosis and meiosis that ensure the resulting daughter cells inherit the appropriate number of chromosomes.

(b) The genetic composition of daughter cells produced by mitosis differs from that of the daughter cells produced by meiosis. **Describe** TWO features of the cell division processes that lead to these differences.

2014 #8

This question is in Unit 7.

Free Response Scoring Guidelines

<table>
<tr><th colspan="2">2024 #1</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>4.5: Cell Cycle
• 4.5.A: Describe the events that occur in the cell cycle.
5.1: Meiosis
• 5.1.A: Explain how meiosis results in the transmission of chromosomes from one generation to the next.
5.2: Meiosis and Genetic Diversity
• 5.2.A: Explain how the process of meiosis generates genetic diversity.
7.3: Artificial Selection
• 7.3.A Explain how humans can affect diversity within a population.
7.11: Variations in Populations
• 7.11.A: Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.</td><td>1.A: Describe biological concepts and processes.
4.A: Construct a graph to represent the data
4.B: Describe data from a table or graph
5.A: Perform mathematical calculations
5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different.
6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.
6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.</td></tr>
</table>

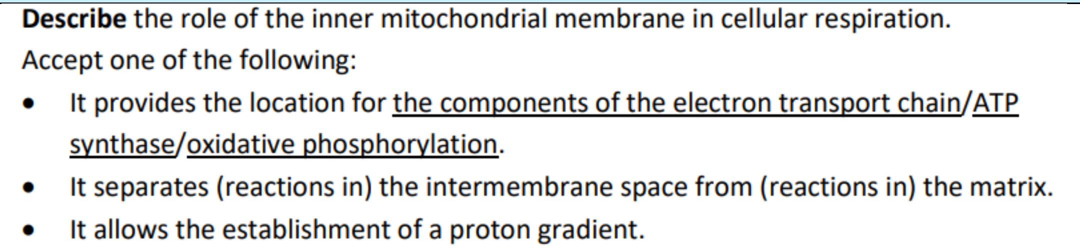
<table>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>Describe the function of S phase of interphase.
Accept one of the following:
• (The function of S phase is to) <u>replicate</u>/<u>duplicate</u>/<u>synthesize</u> the <u>DNA</u>/<u>chromosomes</u>.
• (The function of S phase is to) double the amount of DNA.
Explain why some haploid cells formed after meiosis in this experiment will have only one fluorescent marker.
Accept one of the following:
• Some cells will receive a <u>chromosome</u>/<u>(sister) chromatid</u> that did not undergo <u>crossing over</u>/<u>recombination</u> (in the hotspot).
• Two (or a multiple of two) crossing-over events occurred (in the hotspot).
• Each daughter cell will receive one of the four sister chromatids. Two of the sister chromatids shown in Figure 1 have only one fluorescent protein gene.
• The two chromosomes that were not involved in crossing over will have only the RFP gene or the GFP gene. After meiosis II, a gamete with one of these chromosomes will have only the RFP or the GFP gene.</td></tr>
<tr><td>(b)</td><td>Identify the control group for the scientists' first experiment, shown in <u>Figure 2</u>.
Accept one of the following:
• Group 1
• (The group called) None
• Cells with no (kinetochore) protein (attached to the chromosome)</td></tr>
</table>

	In a follow-up experiment, the scientists created a modified version of CTF in which the DNA-binding portion had been removed. They compared the frequency of crossing over in yeast cells in the presence and absence of unmodified CTF with that in yeast cells in the presence and absence of the modified CTF protein (data not shown). In the follow-up experiment, **justify** why the scientists used a modified CTF protein that is unable to bind to DNA as a control. Accept one of the following: • (Using a modified CTF enabled the scientists) to determine whether DNA binding of the CTF/kinetochore protein affects/inhibits crossing over/recombination. • (Using a modified CTF enabled the scientists) to determine whether just the presence of the CTF/kinetochore protein is enough to affect/inhibit the crossing over/recombination frequency. **Identify** the independent variable in the follow-up experiment. Accept one of the following: • The type of CTF used • The presence or absence of (modified/unmodified) CTF
(c)	Based on Figure 2, **describe** the effect on the frequency of crossing over when CTF is attached to the chromosome 8 hotspot compared with the effect when IML is attached to the hotspot. Accept one of the following: • CTF attachment results in a decreased/lower frequency of crossing over/recombination, (whereas IML had no effect). • IML attachment results in an increased/a higher frequency of crossing over/recombination (compared with CTF attachment).
(d)	**Predict** the effect on the number of copies of chromosome 8 likely to be present in the resulting daughter cells when CTF is attached to the hotspot. Accept one of the following: • There will be zero/two (copies). • There will be one less/one extra (copy). Provide reasoning to **justify** your prediction. • Cells (with attached CTF molecules) undergo crossing over/recombination at a lower frequency, so it is more likely that nondisjunction would occur/chromosomes would not separate properly. **Explain** how the presence of hotspots (Figure 1) could increase the likelihood that a population will survive in the presence of selective pressures. • Hotspots would increase genetic diversity; therefore, it would be more likely that some individuals would survive and reproduce.

Scoring Statistics	
Mean: 3.09	Standard Deviation: 1.67

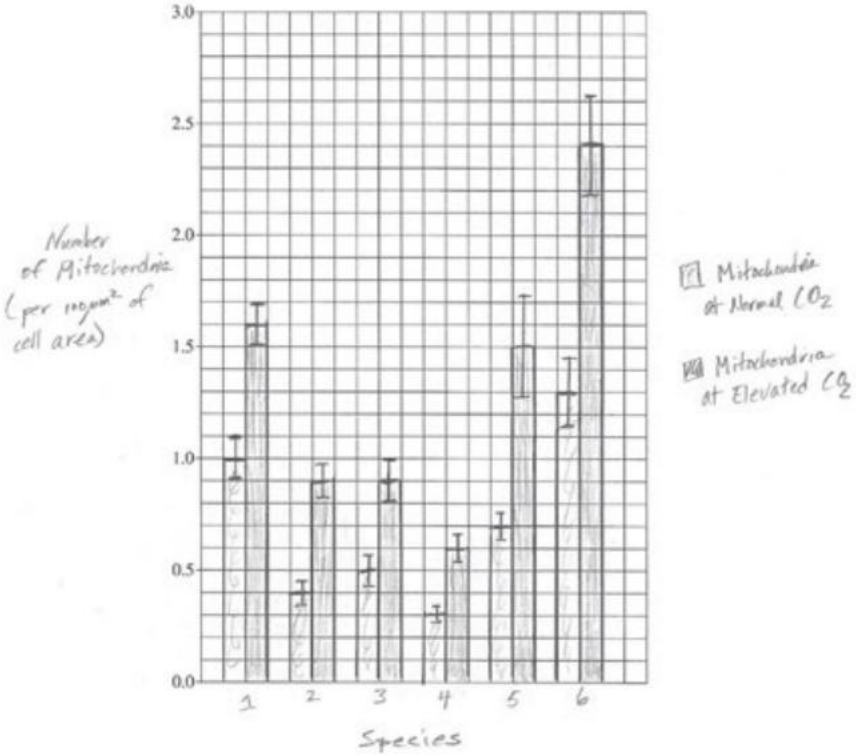
2023 #2	
Course Content	Practice and Skill

3.4: Photosynthesis • 3.4.A: Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy. 2.1: Cell Structure and Function • 2.1.A: Explain how the structure and function of subcellular components and organelles contribute to the function of cells. 5.4: Non-Mendelian Genetics • 5.4.A: Explain deviations from Mendel's model of the inheritance of traits. 5.5: Environmental Effects on Phenotype • 5.5.A: Explain how the same genotype can result in multiple phenotypes under different environmental conditions.	1.A: Describe biological concepts and processes. 4.A: Construct a graph to represent the data 4.B: Describe data from a table or graph 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	 **Describe** the role of the inner mitochondrial membrane in cellular respiration. Accept one of the following: • It provides the location for the components of the electron transport chain/ATP synthase/oxidative phosphorylation. • It separates (reactions in) the intermembrane space from (reactions in) the matrix. • It allows the establishment of a proton gradient.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1.

Sample response:



- Appropriate labelling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1.

- Data are represented in a bar/modified bar graph.

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1.

- Data points and error bars are correctly plotted.

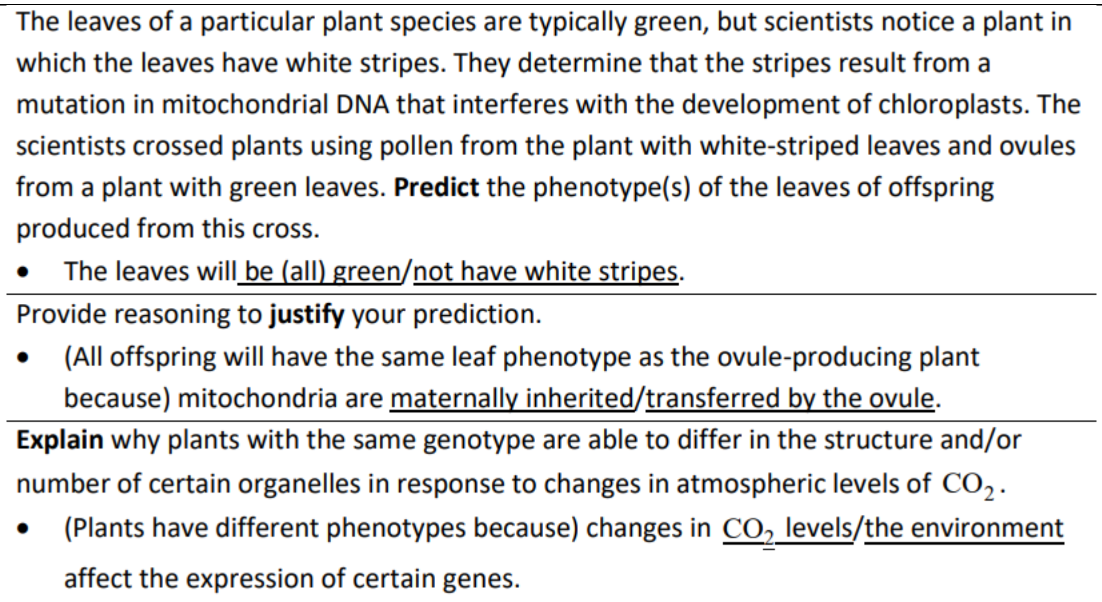
Determine which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2.

- All of the species

(c) Based on the data in Table 1, **describe** the relationship between the level of CO_2 and the average number of mitochondria per unit area of a cell.

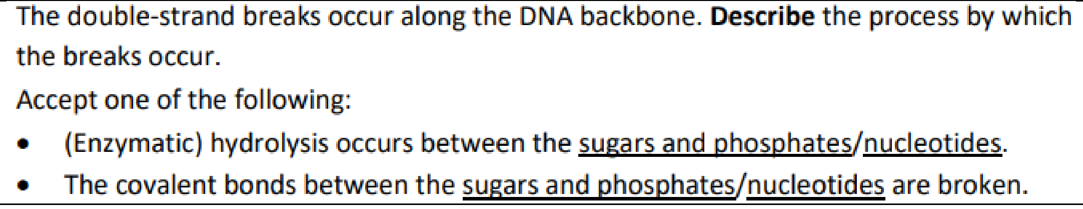
Accept one of the following:

- The number of mitochondria is greater under conditions of elevated CO_2 (than under normal CO_2).
- It is a positive relationship/correlation.

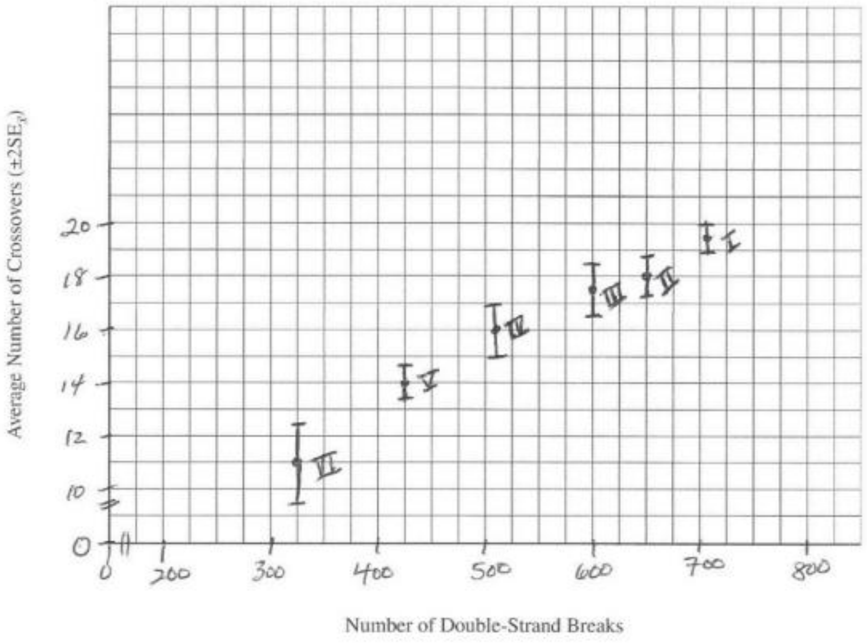
(d)	 The leaves of a particular plant species are typically green, but scientists notice a plant in which the leaves have white stripes. They determine that the stripes result from a mutation in mitochondrial DNA that interferes with the development of chloroplasts. The scientists crossed plants using pollen from the plant with white-striped leaves and ovules from a plant with green leaves. **Predict** the phenotype(s) of the leaves of offspring produced from this cross. • The leaves will be (all) green/not have white stripes. Provide reasoning to **justify** your prediction. • (All offspring will have the same leaf phenotype as the ovule-producing plant because) mitochondria are maternally inherited/transferred by the ovule. **Explain** why plants with the same genotype are able to differ in the structure and/or number of certain organelles in response to changes in atmospheric levels of CO_2. • (Plants have different phenotypes because) changes in CO_2 levels/the environment affect the expression of certain genes.

Scoring Statistics	
Mean: 4.10	Standard Deviation: 2.52

2022 #2	
Course Content	Practice and Skill
1.3: Introduction to Macromolecules • 1.3.A: Describe the chemical reactions that build and break biological macromolecules. 5.2: Meiosis and Genetic Diversity • 5.2.A: Explain how the process of meiosis generates genetic diversity. 6.7: Mutations • 6.7.B: Explain how changes in genotype may result in changes in phenotype.	1.A: Describe biological concepts and processes. 4.A: Construct a graph to represent the data 4.B: Describe data from a table or graph 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines
(a)	 The double-strand breaks occur along the DNA backbone. **Describe** the process by which the breaks occur. Accept one of the following: • (Enzymatic) hydrolysis occurs between the sugars and phosphates/nucleotides. • The covalent bonds between the sugars and phosphates/nucleotides are broken.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers.



- Appropriate axis scaling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers.

- Accurately plotted X,Y graph with separate points for the average number of crossovers for each strain

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers.

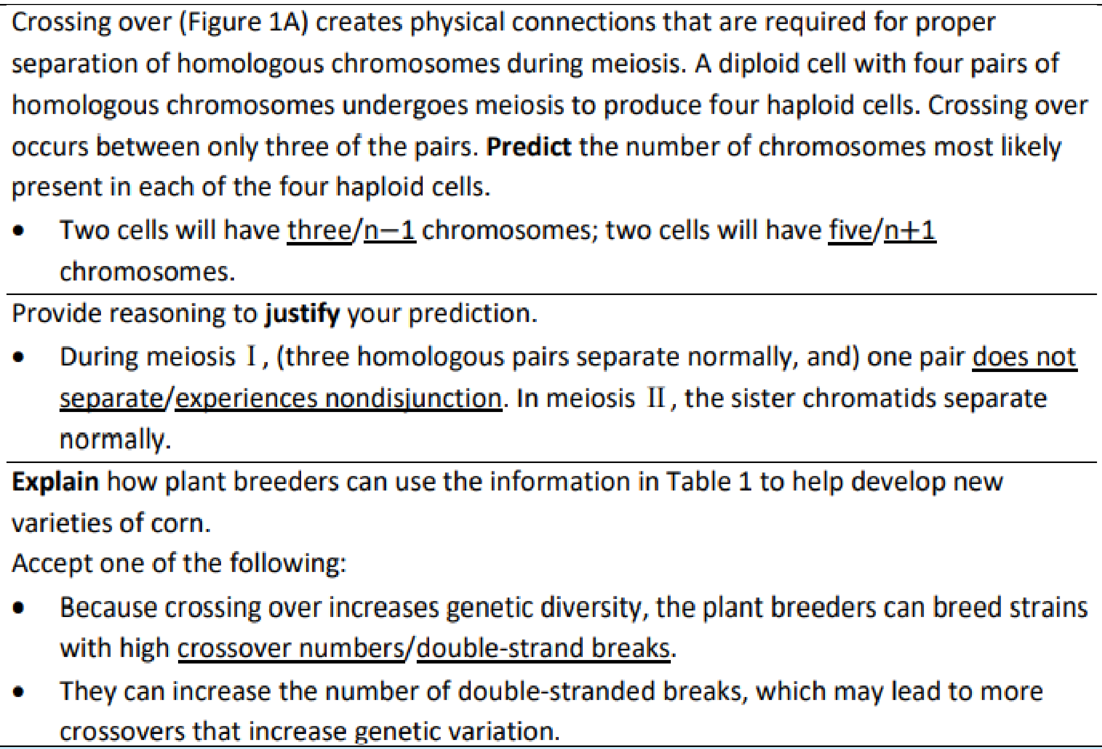
- Accurate error bars

Based on the data, **determine** whether corn strains I, II, and III differ in their average number of crossovers.

- There is no (statistical) difference (in the average number of crossovers) between strains II and III. Strain I is higher/different (in the average number of crossovers) compared with strains II and III.

(c) Based on the data, **describe** the relationship between the average number of double strand breaks and the average number of crossovers in the strains of corn analyzed in the experiment.

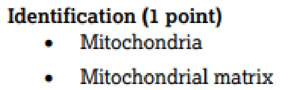
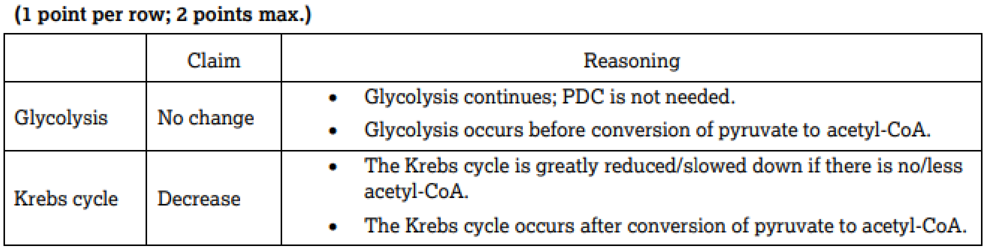
- (In general) there is a direct correlation/positive relationship (between the number of double-strand breaks and the number of chromatid crossovers).

(d)	 Crossing over (Figure 1A) creates physical connections that are required for proper separation of homologous chromosomes during meiosis. A diploid cell with four pairs of homologous chromosomes undergoes meiosis to produce four haploid cells. Crossing over occurs between only three of the pairs. **Predict** the number of chromosomes most likely present in each of the four haploid cells. - Two cells will have three/n−1 chromosomes; two cells will have five/n+1 chromosomes. Provide reasoning to **justify** your prediction. - During meiosis I, (three homologous pairs separate normally, and) one pair does not separate/experiences nondisjunction. In meiosis II, the sister chromatids separate normally. **Explain** how plant breeders can use the information in Table 1 to help develop new varieties of corn. Accept one of the following: - Because crossing over increases genetic diversity, the plant breeders can breed strains with high crossover numbers/double-strand breaks. - They can increase the number of double-stranded breaks, which may lead to more crossovers that increase genetic variation.

Scoring Statistics	
Mean: 2.83	Standard Deviation: 1.78

2019 #3

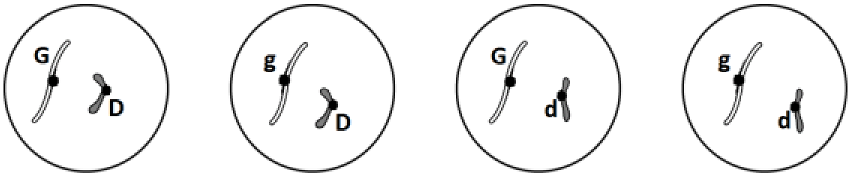
Course Content	Practice and Skill
3.5: Cellular Respiration - 3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions. 5.4: Non-Mendelian Genetics - 5.4.A: Explain deviations from Mendel's model of the inheritance of traits.	1.A: Describe biological concepts and processes. 5.A: Perform mathematical calculations 6.A: Make a scientific claim. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines
(a)	 **Identification (1 point)** - Mitochondria - Mitochondrial matrix
(b)	 **(1 point per row; 2 points max.)**

	Claim	Reasoning
Glycolysis	No change	- Glycolysis continues; PDC is not needed. - Glycolysis occurs before conversion of pyruvate to acetyl-CoA.
Krebs cycle	Decrease	- The Krebs cycle is greatly reduced/slowed down if there is no/less acetyl-CoA. - The Krebs cycle occurs after conversion of pyruvate to acetyl-CoA.

<table>
<tr><td>(c)</td><td>**Calculation (1 point)**
- The probability of inheritance is 0.
- The offspring cannot/will not have PDC deficiency.</td></tr>
<tr><td colspan="2">Scoring Statistics</td></tr>
<tr><td>Mean: 1.68</td><td>Standard Deviation: 1.33</td></tr>
</table>

<table>
<tr><th colspan="2">2016 #7</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>5.1: Meiosis
- 5.1.A: Explain how meiosis results in the transmission of chromosomes from one generation to the next.
5.4: Non-Mendelian Genetics
- 5.4.A: Explain deviations from Mendel's model of the inheritance of traits.
6.1: DNA and RNA Structure
- 6.1.B: Describe the characteristics of DNA that allow it to be used as hereditary material.</td><td>1.A: Describe biological concepts and processes.
2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.
5.A: Perform mathematical calculations</td></tr>
</table>

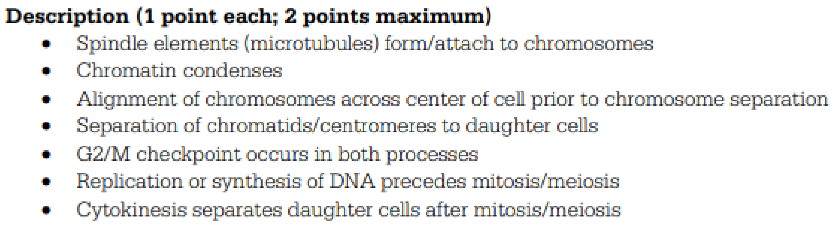
<table>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>**Construct diagram (1 point)**
- Diagram must include all of the following:
o Each cell has one unduplicated chromosome 1 (with G or g).
o Each cell has one unduplicated chromosome 2 (with D or d).
o Genotype combinations should be: GD, Gd, gD, gd.
 </td></tr>
<tr><td>(b)</td><td>**Prediction (1 point)**
- 1 green dwarf: 1 green tall: 1 purple dwarf: 1 purple tall</td></tr>
<tr><td>(c)</td><td>**Identify difference (1 point)**
- The majority/greater than 50 percent would have the parental plant phenotypes
- Greater than 25 percent would be green dwarf plants and greater than 25 percent would be purple tall plants
- Less than 25 percent would be green tall plants and less than 25 percent would be purple dwarf plants</td></tr>
<tr><td colspan="2">Scoring Statistics</td></tr>
<tr><td>Mean: 0.51</td><td>Standard Deviation: 0.82</td></tr>
</table>

2015 #4

Course Content	Practice and Skill
5.1: Meiosis • 5.1.B: Describe similarities and differences between the phases and outcomes of mitosis and meiosis. 5.2: Meiosis and Genetic Diversity • 5.2.A: Explain how the process of meiosis generates genetic diversity.	1.A: Describe biological concepts and processes.

Part — Scoring Guidelines

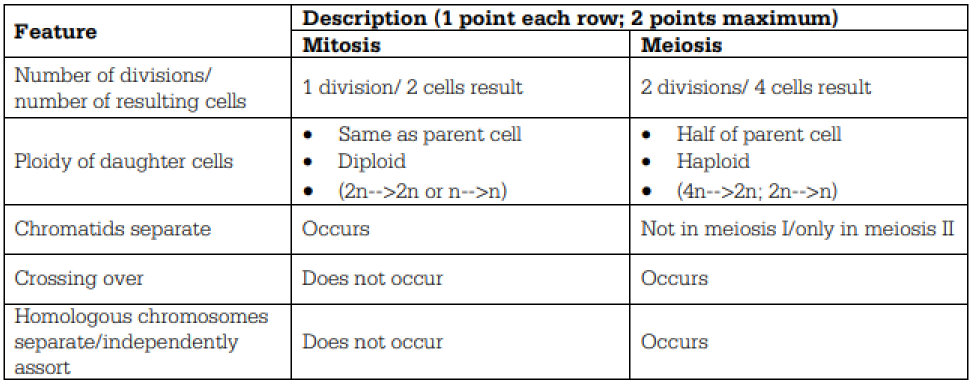
(a)



Description (1 point each; 2 points maximum)

- Spindle elements (microtubules) form/attach to chromosomes
- Chromatin condenses
- Alignment of chromosomes across center of cell prior to chromosome separation
- Separation of chromatids/centromeres to daughter cells
- G2/M checkpoint occurs in both processes
- Replication or synthesis of DNA precedes mitosis/meiosis
- Cytokinesis separates daughter cells after mitosis/meiosis

(b)



Feature	**Description (1 point each row; 2 points maximum)**	
	Mitosis	**Meiosis**
Number of divisions/ number of resulting cells	1 division/ 2 cells result	2 divisions/ 4 cells result
Ploidy of daughter cells	• Same as parent cell • Diploid • (2n-->2n or n-->n)	• Half of parent cell • Haploid • (4n-->2n; 2n-->n)
Chromatids separate	Occurs	Not in meiosis I/only in meiosis II
Crossing over	Does not occur	Occurs
Homologous chromosomes separate/independently assort	Does not occur	Occurs

Scoring Statistics

Mean: 1.47	Standard Deviation: 1.31

Unit 6: Gene Expression and Regulation

Topic	Learning Objective(s)
6.1 DNA and RNA Structure	**6.1.A:** Describe the structures involved in passing hereditary information from one generation to the next. **6.1.B:** Describe the characteristics of DNA that allow it to be used as hereditary material.
6.2 DNA Replication	**6.2.A:** Describe the mechanisms by which genetic information is copied for transmission between generations.
6.3 Transcription and RNA Processing	**6.3.A:** Describe the mechanisms by which genetic information flows from DNA to RNA to protein.
6.4 Translation	**6.4.A:** Explain how the phenotype of an organism is determined by its genotype.
6.5 Regulation of Gene Expression	**6.5.A:** Describe the types of interactions that regulate gene expression. **6.5.B:** Explain how the location of regulatory sequences relates to their function.
6.6 Gene Expression and Cell Specialization	**6.6.A:** Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism. **6.6.B:** Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.
6.7 Mutations	**6.7.A:** Describe the various types of mutation. **6.7.B:** Explain how changes in genotype may result in changes in phenotype. **6.7.C:** Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.
6.8 Biotechnology	**6.8.A:** Explain the use of genetic engineering techniques in analyzing or manipulating DNA.

Additional Resources

Unit 6 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

AP Biology Exam Review

Topic 6.1 DNA and RNA Structure

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.1.A: Describe the structures involved in passing hereditary information from one generation to the next.</td></tr>
<tr><td>6.1.A.1: Genetic information is stored in and passed to subsequent generations through DNA molecules and, in some cases, RNA molecules.
i. Prokaryotic organisms typically have circular chromosomes.
ii. Eukaryotic organisms typically have multiple linear chromosomes that are comprised of DNA. These chromosomes are condensed using histones and associated proteins.</td><td>☐ I can describe the structures involved in passing hereditary information from one generation to the next.
☐ I can describe how genetic information is stored and passed on to subsequent generations.
☐ I can identify differences between prokaryote and eukaryote genome shapes
☐ I can identify differences between amount prokaryote and eukaryotes genome</td></tr>
</table>

1. How is genetic information stored?
2. How is genetic information passed from one generation to the next?
3. How is prokaryotic DNA shaped?
4. How is eukaryotic DNA shaped?
5. How is the amount of DNA different between a prokaryote and a eukaryote?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.1.A: Describe the structures involved in passing hereditary information from one generation to the next.</td></tr>
<tr><td>6.1.A.2: Prokaryotes and eukaryotes can contain plasmids, which are extra-chromosomal circular molecules of DNA.</td><td>☐ I can describe plasmids
☐ I can describe functions of plasmids
☐ I can describe biotechnology uses for plasmids</td></tr>
</table>

6. What is a plasmid?
7. Identify two functions of plasmids.
8. Identify two biotechnical uses for plasmids.

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
6.1.B: Describe the characteristics of DNA that allow it to be used as hereditary material.	
6.1.B.1: Nucleic acids exhibit specific nucleotide base pairing that is conserved through evolution. i. Purines (guanine and adenine) have a double ring structure. ii. Pyrimidines (cytosine, thymine, and uracil) have a single ring structure. iii. Purines pair with pyrimidines: adenine with thymine (or uracil in RNA) and guanine with cytosine.	☐ I can describe characteristics of DNA that allow it to be used as hereditary material ☐ I can describe the nucleotide base pairing ☐ I can describe the structure of purines ☐ I can describe the structure of pyrimidines ☐ I can determine the number of other nucleotides based on a given number of one nucleotide.

9. Why is DNA a better hereditary material than RNA?
10. What are the nucleotide base pairing rules?
11. What is the structure of a purine?
    a. Which of the nitrogenous bases are purines?
12. What is the structure of a pyrimidine?
    a. Which of the nitrogenous bases are pyrimidines?
13. Why does a purine always pair with a pyrimidine?
14. If there is 20% thymine in a DNA strand, how much cytosine is there?

Topic 6.2: DNA Replication

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.2.A: Describe the mechanisms by which genetic information is copied for transmission between generations.</td></tr>
<tr><td>6.2.A.1: DNA replication ensures continuity of hereditary information.
i. DNA is synthesized in the 5' to 3' direction.
ii. Replication is a semiconservative process, meaning one strand of DNA serves as the template for a new strand of complementary DNA.
iii. Helicase unwinds the DNA strands.
iv. Topoisomerase relaxes supercoiling in front of the replication fork.
v. DNA polymerase requires RNA primers to initiate DNA synthesis.
vi. DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand.
vii. Ligase joins the fragments on the lagging strand.
☒ Exclusion Statement:
The names of the steps and particular enzymes involved, excluding DNA polymerase, ligase, RNA polymerase, helicase, and topoisomerase, are beyond the scope of the AP Exam.</td><td>☐ I can describe the mechanisms that genetic information is copied
☐ I can describe the directionality of DNA synthesis
☐ I can describe the process of DNA replication
☐ I can describe the function of helicase
☐ I can describe the function of topoisomerase
☐ I can describe the function of RNA primers
☐ I can describe the function of Primase
☐ I can describe the differences between the leading and lagging strand
☐ I can describe the function of DNA ligase</td></tr>
</table>

1. What direction is DNA synthesized?
    a. What direction does the DNA polymerase READ the DNA template?
2. What is the function of helicase?
3. What is the function of topoisomerase?
4. What is the function of DNA polymerase?
5. What is the function of RNA primers and primase?
6. Why are RNA primers required for DNA replication?
7. How does the leading and the lagging strand differ?
8. What is the function of DNA ligase?
9. Describe the process of DNA replication using the enzymes described above (helicase, topoisomerase, DNA polymerase, primase, RNA primers, and DNA ligase)

Topic 6.3: Transcription and RNA Processing

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein.</td></tr>
<tr><td>6.3.A.1: The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function.
i. Messenger RNA (mRNA) molecules carry information from DNA in the nucleus to the ribosome in the cytoplasm.
ii. Distinct transfer RNA (tRNA) molecules bind specific amino acids and have anticodon sequences that base pair with the codons of mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence.
iii. Ribosomal RNA (rRNA) molecules are functional building blocks of ribosomes.</td><td>☐ I can describe the mechanisms by which genetic information flows from DNA to RNA to protein
☐ I can describe what determines RNA function.
☐ I can describe the function of mRNA
☐ I can describe the function of tRNA
☐ I can describe the function of rRNA
☐ I can describe the interaction between rRNA, mRNA, and tRNA</td></tr>
</table>

1. What determines RNA function?
2. What is the function of mRNA?
3. What is the function of tRNA?
4. What is the function of rRNA?
5. How does the mRNA, tRNA, and rRNA all interact?
6. How does the DNA sequence determine the RNA sequence?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein.</td></tr>
<tr><td>6.3.A.2: RNA polymerases use a single template strand of DNA to direct the inclusion of bases in the newly formed RNA molecule. This process is known as transcription.</td><td>☐ I can describe transcription</td></tr>
</table>

7. What is transcription?
8. What is the starting material for transcription?
9. What is the product of transcription?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein.</td></tr>
<tr><td>6.3.A.3: The enzyme RNA polymerase synthesizes mRNA molecules in the 5’ to 3’ direction by reading the template DNA strand in the 3’ to 5’ direction.</td><td>☐ I can describe the function of RNA polymerase
☐ I can describe the directionality of transcription</td></tr>
</table>

10. What is the function of RNA polymerase?
11. Which strand is the template strand?
12. Which direction does transcription take place (which direction is the RNA synthesized)?
    a. Which direction is the template strand READ?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein.</td></tr>
<tr><td>6.3.A.4: In eukaryotic cells the mRNA transcript undergoes a series of enzyme-mediated modifications.
i. The addition of a poly-A tail makes mRNA more stable.
ii. The addition of a GTP cap helps with ribosomal recognition.
iii. The excision of introns, along with the splicing and retention of exons, generates different versions of the resulting mature mRNA molecule. This process is known as alternative splicing.</td><td>☐ I can describe post-transcriptional modifications
☐ I can describe the function of the poly-A tail
☐ I can describe the function of the GTP cap
☐ I can describe the function of RNA splicing
☐ I can describe alternative splicing</td></tr>
</table>

13. Describe the process that takes place during transcription.
14. Identify three post-transcriptional modifications that alter the pre-mRNA prior to its release from the nucleus.
15. What is the function of the poly-A tail?
16. What is the function of the GTP cap?
17. What is the function of RNA splicing?
18. How can multiple proteins be synthesized from the same mRNA transcript?

Topic 6.4: Translation

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.4.A: Explain how the phenotype of an organism is determined by its genotype.</td></tr>
<tr><td>6.4.A.1: Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells, as well as the cytoplasmic surface of the rough ER of eukaryotic cells.</td><td>☐ I can describe ways the phenotype of an organism is determined by the phenotype
☐ I can identify the location of translation
☐ I can describe differences between location of translation in prokaryotes and eukaryotes</td></tr>
</table>

1. What is translation?
2. Where does translation take place?
3. How does the location of translation differ between a prokaryote and a eukaryote?
    a. How does the location of translation affect gene expression in a prokaryote?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.4.A: Explain how the phenotype of an organism is determined by its genotype.</td></tr>
<tr><td>6.4.A.2: In prokaryotic organisms, translation of the mRNA molecule occurs while it is being transcribed.</td><td>☐ I can describe why prokaryotes complete translation concurrently with transcription</td></tr>
</table>

4. How is a prokaryote able to translate concurrently with transcription?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.4.A: Explain how the phenotype of an organism is determined by its genotype.</td></tr>
<tr><td>6.4.A.3: Translation involves many sequential steps, including initiation, elongation, and termination. The salient features of translation include:
i. Translation is initiated when the rRNA in the ribosome interacts with the mRNA at the start codon (AUG, coding for the amino acid methionine).
ii. The sequence of nucleotides on the mRNA is read in triplets, called codons.
iii. Each codon encodes a specific amino acid, which can be deduced by using a genetic code chart. Many amino acids are encoded by more than one codon.</td><td>☐ I can describe the process of translation.
☐ I can describe the initiation step of translation
☐ I can describe the elongation step of translation
☐ I can describe the termination step of translation
☐ I can identify where translation starts
☐ I can describe a codon
☐ I can determine the appropriate amino acid for a codon
☐ I can describe why multiple codons are able to code for the same amino acid
☐ I can use genetic code as evidence for common ancestry
☐ I can describe the three sites of a ribosome</td></tr>
</table>

iv. Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms. v. tRNA brings the correct amino acid to the place specified by the codon on the mRNA. vi. The amino acid is transferred to the growing polypeptide chain. vii. The process continues along the mRNA until a stop codon is reached. vii. Translation terminates with the release of the newly synthesized protein. ☒ **Exclusion Statement:** The details and names of the enzymes and factors involved in each of these steps are beyond the scope of the AP Exam. ☒ **Exclusion Statement:** Memorization of the genetic code, with the exception of the start codon AUG, is beyond the scope of the AP Exam.	☐ I can describe the chemical process that releases the growing polypeptide

5. What are the three steps of translation?
6. What happens in the initiation step of translation?
7. Where does translation start?
8. What is a codon?
    a. How many nucleotides make up a codon?
9. Practice using a codon chart:
    a. What amino acid is coded by UAU?
    b. What codons code for lysine?
10. How are multiple codons able to code for the same amino acids?
11. True or False: One codon can code for more than one amino acid.
12. What are the three sites found on a ribosome and what is their function?
13. What happens in the elongation step of translation?
14. What happens in the termination step of translation?
15. What chemical process releases the growing polypeptide?
16. How does the genetic code demonstrate common ancestry?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.4.A: Explain how the phenotype of an organism is determined by its genotype.</td></tr>
<tr><td>6.4.A.4: Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and is transcribed and translated for the assembly of new viral progeny.</td><td>☐ I can describe ways that retroviruses violate the central dogma
☐ I can describe the function of reverse transcriptase
☐ I can describe the ways that retroviruses incorporate viral genome in host genome
☐ I can describe how new viral progeny is formed</td></tr>
</table>

17. What is the central dogma?
    a. How does a retrovirus violate this process?
    b. Identify two examples of retroviruses.
18. What is the function of reverse transcriptase?
19. How does a virus incorporate its viral genome into a host genome?
20. How does a virus form progeny viruses?

Topic 6.5: Regulation of Gene Expression

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
6.5.A: Describe the types of interactions that regulate gene expression.	
6.5.A.1: Regulatory sequences are stretches of DNA that interact with regulatory proteins to control transcription. Some genes are constitutively expressed, and others are inducible.	☐ I can describe the types of interactions that regulate gene expression. ☐ I can describe the function of regulatory sequences

1. What are regulatory sequences?
2. What is the promoter region?
3. What is the TATA box?
4. What is the enhancer region?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
6.5.A: Describe the types of interactions that regulate gene expression.	
6.5.A.2: Epigenetic changes can affect gene expression through reversible modifications of DNA or histones.	☐ I can describe epigenetic changes ☐ I can describe modifications to DNA to regulate gene expression ☐ I can describe modifications to histones to regulate gene expression

5. What are epigenetic changes?
6. How is DNA modified to initiate transcription (to regulate gene expression)?
7. How is DNA modified to inhibit transcription (to regulate gene expression)?
8. How are histones modified to initiate transcription (to regulate gene expression)?
9. How are histone modified to inhibit transcription (to regulate gene expression)?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
6.5.A: Describe the types of interactions that regulate gene expression.	
6.5.A.3: The phenotype of a cell or an organism is determined by the combination of genes that are expressed and the levels at which they are expressed. i. Observable cell differentiation results from the expression of genes for tissue-specific proteins.	☐ I can describe how the phenotype of a cell or organism is determined ☐ I can describe cell differentiation ☐ I can explain why different phenotypes appear at different levels of gene expression ☐ I can describe the function of transcription factors ☐ I can describe the function of gene products on the phenotype of organisms

ii. Induction of transcription factors during development results in sequential gene expression. iii. The function and amount of gene products determine the phenotype of organisms	☐ I can describe the function of amount of gene products on the phenotype of organisms

10. True or False: All somatic cells have the same DNA.
11. What is cell differentiation?
12. Why can different phenotypes result from different levels of gene expression?
13. What is the function of transcription factors?
14. How do gene products affect the phenotype of organisms?
15. How do the amount of gene products affect the phenotype of organisms?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
6.5.B: Explain how the location of regulatory sequences relates to their function.	
6.5.B.1: Both prokaryotes and eukaryotes have groups of genes that are coordinately regulated. i. Prokaryotes regulate operons in an inducible or repressible system. ii. In eukaryotes, groups of genes may be influenced by the same transcription factors to coordinately regulate expression.	☐ I can explain how the location of regulatory sequences relates to their function ☐ I can explain ways prokaryote gene expression is regulated ☐ I can explain ways eukaryote gene expression is regulated ☐ I can describe the function of an operon ☐ I can explain the interaction between repressors and promoters

16. How is prokaryotic gene expression regulated?
17. What is an operon?
18. What is a repressor?
19. What is a promoter?
20. Describe the interaction between repressors and promoters.
21. How does the repressor interact with the promoter?
22. Describe the lac operon.
    a. What happens when lactose is present?
    b. What happens when lactose is absent?
    c. Is this operon repressible or inducible?
23. Describe the trp operon.
    a. What happens when tryptophan is present?
    b. What happens when tryptophan is absent?
24. Is this operon repressible or inducible?
25. How is eukaryotic gene expression regulated?

Topic 6.6: Gene Expression and Cell Specialization

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.6.A: Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism.</td></tr>
<tr><td>6.6.A.1: RNA polymerase and transcription factors bind to promoter or enhancer DNA sequences to initiate transcription. These sequences can be upstream or downstream of the transcription start site.</td><td>☐ I can explain how the binding of transcription factors to promoter regions affect gene expression
☐ I can explain how the binding of transcription factors to promoter regions affect the phenotype of the organism
☐ I can explain the function of transcription factors
☐ I can explain the function of RNA polymerase
☐ I can explain the function of the promoter</td></tr>
</table>

1. How do transcription factors affect the binding at the promoter?
2. Describe the difference between a promoter or enhancer.
3. What is the function of transcription factors?
4. What is the function of RNA polymerase?
5. What is the function of the promoter?
6. How do negative regulatory molecule inhibit gene expression?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.6.A: Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism.</td></tr>
<tr><td>6.6.A.2: Negative regulatory molecules inhibit gene expression by binding to DNA and blocking transcription.</td><td>☐ I can explain ways negative regulatory molecules inhibit gene expression</td></tr>
</table>

7. Identify TWO negative regulatory molecules that inhibit gene expression.
8. Explain how negative regulatory molecules inhibit gene expression.

AP Biology Exam Review

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.6.B: Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.</td></tr>
<tr><td>6.6.B.1: Gene regulation results in differential gene expression and influences cell products and functions.</td><td>☐ I can explain the connection between the regulation of gene expression and phenotypic differences in cells
☐ I can explain the connection between the regulation of gene expression and phenotypic differences in organisms
☐ I can describe differential gene expression
☐ I can explain the influence of differential gene expression on cell products
☐ I can explain the influence of differential gene expression on cell function</td></tr>
</table>

9. What is differential gene expression?
10. How can differential gene expression affect the cellular products?
11. How can differential gene expression affect the cellular functions?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.6.B: Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.</td></tr>
<tr><td>6.6.B.2: Certain small RNA molecules have roles in regulating gene expression.</td><td>☐ I can describe the regulatory functions of RNA on gene expression</td></tr>
</table>

12. What is siRNA?
13. What is mrRNA?
14. How do siRNA and miRNA affect gene expression?

Topic 6.7: Mutations

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.7.A: Describe the various types of mutation.</td></tr>
<tr><td>6.7.A.1: Alterations in a DNA sequence are mutations that can cause changes in the type or amount of the protein produced and the consequent phenotype. DNA mutations can be beneficial, detrimental, or neutral based on the effect or the lack of effect they have on the resulting nucleic acid or protein and the phenotypes that are conferred by the protein.
i. Point mutations occur when one nucleotide has been substituted for a different nucleotide.
ii. Frameshift mutations occur when one or more nucleotides are inserted or deleted, causing the reading frame to be shifted.
iii. Nonsense mutations occur when there is a point mutation that causes a premature stop.
iv. Silent mutations occur when the change in the nucleotide sequence has no effect on the amino acid sequence.
☒ Exclusion Statement:
Knowledge of specific mutations and their effects is beyond the scope of the AP Exam.</td><td>☐ I can describe the various types of mutations
☐ I can describe a mutation
☐ I can describe ways a mutation can have a beneficial effect on the protein produced
☐ I can describe ways a mutation can have a detrimental effect on the protein produced
☐ I can describe ways a mutation can have a neutral effect on the protein produced
☐ I can describe a point mutation
☐ I can describe a frameshift mutation
☐ I can describe a nonsense mutation
☐ I can describe a silent mutation</td></tr>
</table>

1. What is a mutation?
    a. Identify TWO examples of mutations.
2. How can a mutation have a positive effect on the product produced?
3. How can a mutation have a negative effect on the product produced?
4. How can a mutation have a neutral effect on the product produced?
5. What is a point mutation?
6. What are the three types of substitution point mutations?
    a. How does each affect the protein product?
    b. How does each affect the amount of the protein product?
7. What is a frameshift mutation?
8. What happens if an insertion or deletion occurs at a nucleotide base pair?

   a. How does this affect the protein product?
   b. How does this affect the amount of the protein product?

<table>
<tr><td colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</td></tr>
<tr><td colspan="2">6.7.B: Explain how changes in genotype may result in changes in phenotype.</td></tr>
<tr><td>6.7.B.1: Errors in DNA replication or DNA repair mechanisms as well as external factors, including radiation and reactive chemicals, can cause random mutations in the DNA.
i. Whether a mutation is beneficial, detrimental, or neutral depends on the environmental context.
ii. Mutations are a source of genetic variation.</td><td>☐ I can describe how errors in DNA replication affect mutations
☐ I can describe causes of errors in DNA replication
☐ I can describe DNA repair mechanisms
☐ I can describe why a mutation can be detrimental, beneficial, or neutral
☐ I can identify mutations as a cause of genetic variation</td></tr>
</table>

9. What causes errors in DNA replication?
10. What is involved in the cell's DNA repair mechanisms?
11. How can a mutation be…
    a. Detrimental?
    b. Beneficial?
    c. Neutral?
12. What is the cause of new genetic variation?

<table>
<tr><td colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</td></tr>
<tr><td colspan="2">6.7.B: Explain how changes in genotype may result in changes in phenotype.</td></tr>
<tr><td>6.7.B.2: Errors in mitosis or meiosis can result in changes in phenotype.
i. Changes in chromosome number resulting from nondisjunction often result in new phenotypes caused by triploidy (aneuploidy).
ii. Changes in chromosome number often result in disorders with developmental limitations.
iii. Alterations in chromosome structure lead to genetic disorders.
☒ Exclusion Statement:
Knowledge of specific disorders related to changes in chromosome number is beyond the scope of the AP Exam.</td><td>☐ I can describe errors in mitosis that result in changes in phenotype
☐ I can describe errors in meiosis that result in changes in phenotype
☐ I can describe triploidy
☐ I can describe changes in chromosome number results in disorders with developmental limitations
☐ I can describe changes in chromosome structure results in genetic disorders</td></tr>
</table>

13. Identify an error in mitosis that leads to a change in phenotype.
14. Identify an error in meiosis that leads to a change in phenotype.
15. What does it mean if an organism is a triploid?
16. How do triploids form?
17. Why is a triploid organism usually sterile?
18. Describe how the change in chromosome structure leads to genetic disorders.

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.7.C: Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.</td></tr>
<tr><td>6.7.C.1: Changes in genotype may affect phenotypes that are subject to natural selection. Genetic changes that enhance survival and reproduction can be selected for by environmental conditions.
i. The horizontal acquisitions of genetic information in prokaryotes via transformation (uptake of DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase genetic variation.
ii. Related viruses can recombine genetic information if they infect the same host cell.
iii. Reproductive processes that increase genetic variation are evolutionarily conserved and are shared by various organisms.</td><td>☐ I can explain ways alterations in DNA sequences contribute to variation subject to natural selection
☐ I can explain ways changes in genotype affects phenotypes
☐ I can explain ways phenotypes are subject to natural selection
☐ I can explain ways genotypes are subject to natural selection
☐ I can explain ways that genetic changes enhance survival and are selected for
☐ I can describe ways horizontal transfer of genetic information increases variation
☐ I can describe ways related viruses can recombine genetic information
☐ I can describe reproductive processes that increase genetic variation and are evolutionarily conserved</td></tr>
</table>

19. How does a change in genotype affect the phenotype?
20. True or False: Natural selection acts on genotype.
21. How does a genetic changes enhance survival?
22. How does natural selection affect phenotypes?
23. How does natural selection affect genotypes?
24. What is horizontal transfer?
25. How does horizontal transfer increase variation?

26. What is transformation?
27. What is transduction?
28. What is conjugation?
29. What is transposition?
30. How do viruses recombine genetic information?
31. What reproductive processes increase genetic variation?

Topic 6.8: Biotechnology

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">6.8.A: Explain the use of genetic engineering techniques in analyzing or manipulating DNA.</td></tr>
<tr><td>6.8.A.1: Genetic engineering techniques can be used to analyze and manipulate DNA and RNA.
i. Gel electrophoresis is a process that separates DNA fragments by size and charge.
ii. During polymerase chain reaction (PCR), DNA fragments are amplified by denaturing DNA, annealing primers to the original strand, and extending the new DNA molecule.
iii. Bacterial transformation introduces foreign DNA into bacterial cells.
iv. DNA sequencing technology determines the order of nucleotides in a DNA molecule. Typically, these techniques result in a DNA fingerprint that allows for the comparison of DNA sequences from various samples.

☒ Exclusion Statement:
Knowledge of the details of each of these genetic engineering techniques is beyond the scope of the AP Exam.</td><td>☐ I can explain the use of genetic engineering in analyzing DNA and RNA
☐ I can explain the use of genetic engineering in manipulating DNA and RNA
☐ I can describe the function of electrophoresis
☐ I can describe the function of PCR
☐ I can describe the function of bacterial transformation
☐ I can determine the function of DNA sequencing
☐ I can determine the most appropriate technique for application</td></tr>
</table>

1. How is genetic engineering used to analyze DNA?
2. How is genetic engineering used to manipulate DNA?
3. What is gel electrophoresis?
    a. What is the function of gel electrophoresis?
    b. What occurs during gel electrophoresis?
    c. What information can be drawn from a gel electrophoresis?
    d. Identify an example of when a gel electrophoresis should be done.
4. What is PCR?
    a. What is the function of PCR?
    b. What occurs during a PCR?
    c. Identify an example of when a PCR should be done.
5. What is bacterial transformation?
    a. What is the function of bacterial transformation?
    b. What occurs during a bacterial transformation?

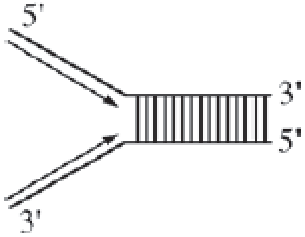
   c. What information can be drawn from a bacterial transformation?
   d. Identify an example of when a bacterial transformation should be done.

6. What is DNA sequencing?
   a. What is the function of DNA sequencing?
   b. What occurs during the process of DNA sequencing?
   c. What information can be drawn from DNA sequencing?
   d. Identify an example of when DNA sequencing should be done.

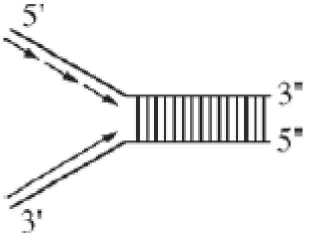
Multiple Choice Practice

1. When DNA replicates, each strand of the original DNA molecule is used as a template for the synthesis of a second, complementary strand. Which of the following figures most accurately illustrates enzyme-mediated synthesis of new DNA at a replication fork?

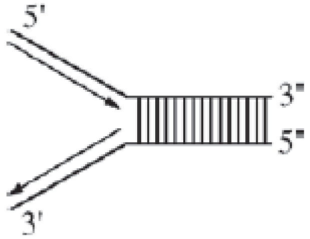
a.



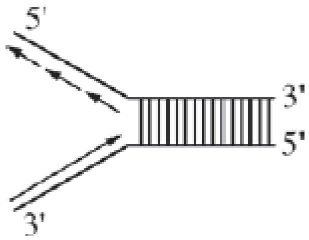
b.



c.

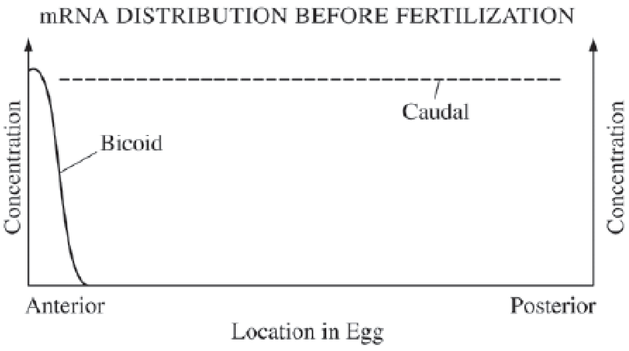


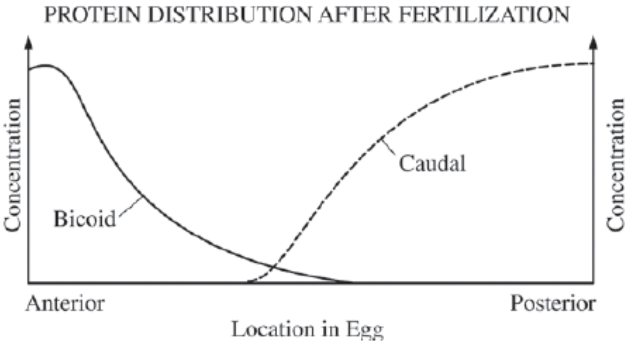
d.



2. The human TPM1 gene encodes members of the tropomyosin family of cytoskeletal proteins. Which of the following best explains how different proteins can be made in different cell types from the one TPM1 gene?
   a. Different introns are selectively converted to exons.
   b. Different exons are retained or spliced out of the primary transcript.
   c. The GTP cap is selectively added to and activates different exons.
   d. Different portions of the primary transcript remain bound to the template DNA.

3. The first diagram below shows the levels of mRNA from two different genes (bicoid and caudal) at different positions along the anterior-posterior axis of a Drosophila egg immediately before fertilization. The second diagram shows the levels of the two corresponding proteins along the anterior-posterior axis shortly after fertilization.





Which of the following conclusions is best supported by the data?

a. Bicoid protein inhibits translation of caudal mRNA.
b. Bicoid protein stabilizes caudal mRNA.
c. Translation of bicoid mRNA produces caudal protein.
d. Caudal protein stimulates development of anterior structures.

Use the following information to answer questions 4 & 5:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

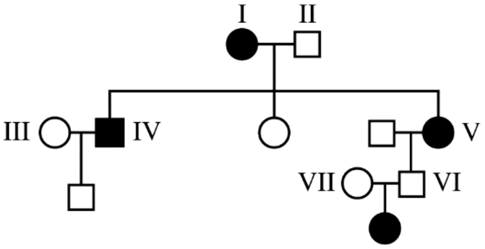


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3' Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5' Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.

Second Base in Codon

First Base in Codon	U	C	A	G	Third Base in Codon
U	UUU, UUC Phe UUA, UUG Leu	UCU, UCC, UCA, UCG Ser	UAU, UAC Tyr UAA Stop UAG Stop	UGU, UGC Cys UGA Stop UGG Trp	U C A G
C	CUU, CUC, CUA, CUG Leu	CCU, CCC, CCA, CCG Pro	CAU, CAC His CAA, CAG Gln	CGU, CGC, CGA, CGG Arg	U C A G
A	AUU, AUC, AUA Ile AUG Met or Start	ACU, ACC, ACA, ACG Thr	AAU, AAC Asn AAA, AAG Lys	AGU, AGC Ser AGA, AGG Arg	U C A G
G	GUU, GUC, GUA, GUG Val	GCU, GCC, GCA, GCG Ala	GAU, GAC Asp GAA, GAG Glu	GGU, GGC, GGA, GGG Gly	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

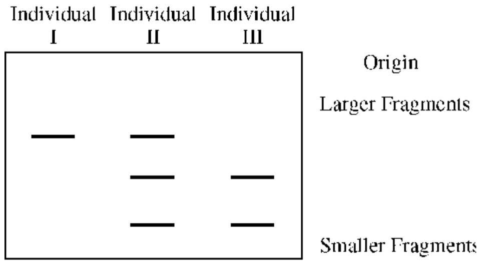
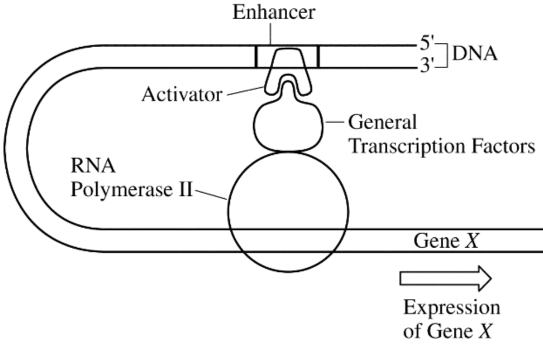


Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

4. The HbS allele, which causes sickle-cell disease, results from a mutation in the DNA sequence shown in Figure 2 that produces a valine (val) in the place of a glutamic acid (glu) residue in the hemoglobin protein. Which of the following mRNA sequences is derived from the HbS allele?
   a. 5' GAC TGA GGA CTC CTC TTC AGA 3'
   b. 5' UCU GAA GAG GAA UCC UCA GUC 3'
   c. 5' AGA CTT CTC CTC AGG AGT CAG 3'
   d. 5' CUG ACU CCU GUG GAG AAG UCU 3'

5. The restriction endonuclease Mst II recognizes the sequence 5' CCT(N)AG (where N = any nucleotide) and cuts DNA at that site, producing separate fragments. Which of the following best explains the banding patterns exhibited in Figure 4?
   a. The HbA DNA contains a recognition site for the Mst II restriction enzyme.
   b. The HbA/HbS DNA contains three recognition sites for the Mst II restriction endonuclease.
   c. Individual I has only one copy of the hemoglobin gene; therefore there is only one band on the gel.
   d. The HbS/HbA DNA contains three different alleles for sickle-cell disease.

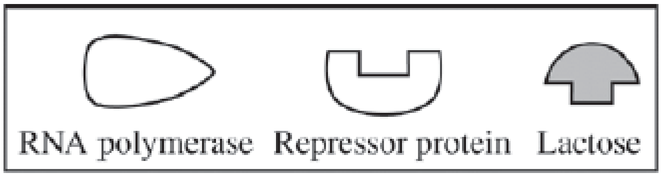
6. The figure to the right depicts the DNA-protein complex that is assembled at the transcriptional start site of gene X when the expression of gene X is activated in liver cells. Previous studies have shown that gene X is never expressed in nerve cells. Based on the diagram, which of the following most likely contributes to the specific expression pattern of gene X?

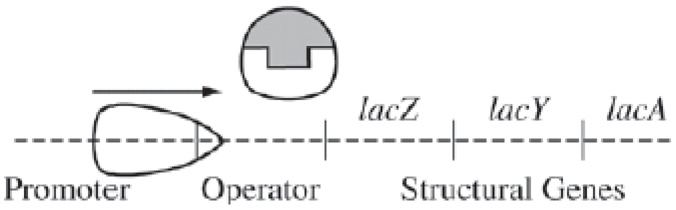


   a. Expression of gene X produces large amounts of tRNA but undetectable amounts of mRNA.
   b. The general transcription factors inhibit the activation of gene X in liver cells by blocking the activator from binding to RNA polymerase II.
   c. The activator is a sequence-specific DNA-binding protein that is present in some tissues but not in other tissues.
   d. The enhancer is a unique DNA segment that is added to the nuclear DNA of some cells of an organism during the process of mitotic cell division but not other cells.

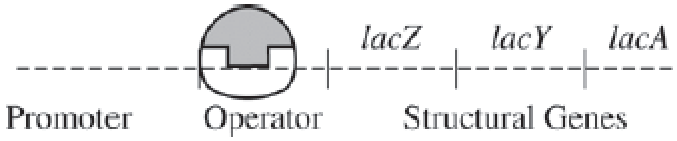
7. Lactose digestion in E. coli begins with its hydrolysis by the enzyme b-galactosidase. The gene encoding b-galactosidase, lacZ, is part of a coordinately regulated operon containing other genes required for lactose utilization.

   Which of the following figures correctly depicts the interactions at the lac operon when lactose is NOT being utilized? (The legend below defines the shapes of the molecules illustrated in the options.)

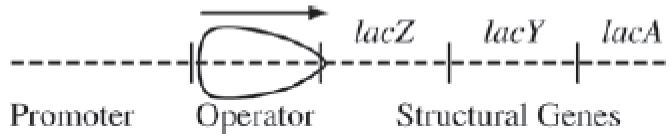




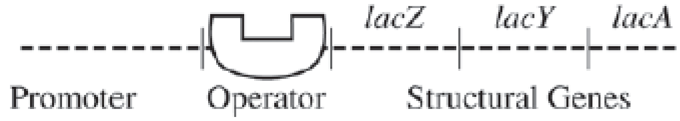
a.



b.



c.



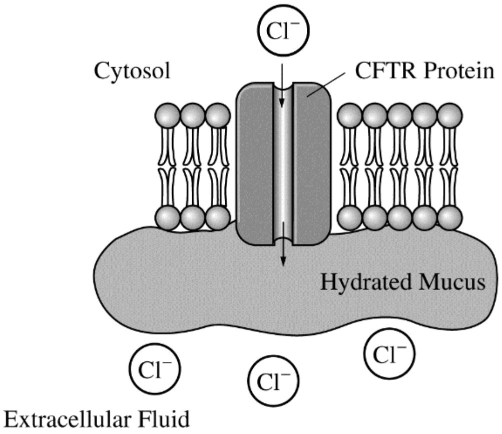
d.

8. Mutations in the MYO6 and POU4F3 genes have been associated with a form of hereditary hearing loss in humans. Researchers studying the genes have proposed that POU4F3 encodes a transcription factor that influences the regulation of MYO6.

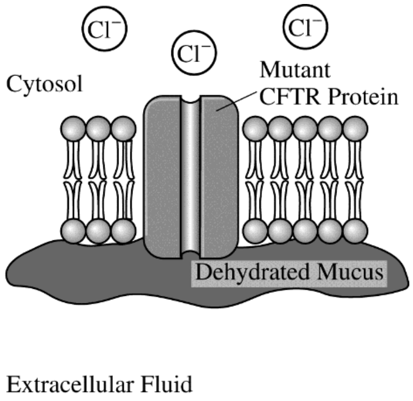
   Which of the following questions will best help guide the researchers toward a direct test of their proposal?
   a. Have mutations in other genes also been associated with hearing loss?
   b. In what types of cells are the mutant forms of the POU4F3 gene expressed?
   c. Are mutations in the MYO6 and POU4F3 genes also found in mice?
   d. Do mutations in the POU4F3 gene affect MYO6 mRNA levels in cells?

9. Sickle-cell anemia results from a point mutation in the HBB gene. The mutation results in the replacement of an amino acid that has a hydrophilic R-group with an amino acid that has a hydrophobic R-group on the exterior of the hemoglobin protein. Such a mutation would most likely result in altered
   a. properties of the molecule as a result of abnormal interactions between adjacent hemoglobin molecules
   b. DNA structure as a result of abnormal hydrogen bonding between nitrogenous bases
   c. fatty acid structure as a result of changes in ionic interactions between adjacent fatty acid chains
   d. protein secondary structure as a result of abnormal hydrophobic interactions between R-groups in the backbone of the protein

10. Cystic fibrosis is a recessively inherited disorder that results from a mutation in the gene encoding CFTR chloride ion channels located on the surface of many epithelial cells. As shown in the figure, the mutation prevents the normal movement of chloride ions from the cytosol of the cell to the extracellular fluid. As a consequence of the mutation, the mucus layer that is normally present on the surface of the cells becomes exceptionally dehydrated and viscous.



Normal



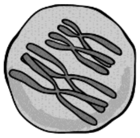
Cystic Fibrosis

An answer to which of the following questions would provide the most information about the association between the CFTR mutation and the viscous mucus?

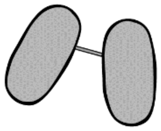
- a. Is the mucus also secreted from the cells through the CFTR proteins?
- b. How does the disrupted chloride movement affect the movement of sodium ions and water by the cell?
- c. How does the mutation alter the structure of the CFTR proteins?
- d. What is the change in nucleotide sequence that results in the CFTR mutation?

11. The processes illustrated in the models depicted below all result in which of the following?

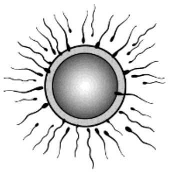
- a. Transcription
- b. An increase in genetic variation
- c. An increase in the chromosome number
- d. Horizontal gene transfer



Crossing Over



Conjugation



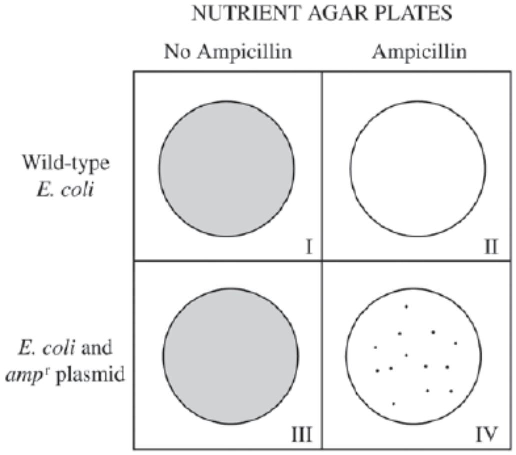
Fertilization

12. A new mutation that arose in one copy of gene X in a somatic cell resulted in the formation of a tumor. Which of the following pieces of evidence best describes how the new mutation directly caused the tumor?

- a. Protein X normally stimulates cell division, and the mutation created an overactive version of protein X.
- b. Protein X normally activates a growth hormone receptor, and the mutation decreased the stability of protein X.
- c. Protein X normally prevents passage through the cell cycle, and the mutation created an overactive version of protein X.
- d. Protein X normally regulates gene expression, and the mutation created an underactive version of protein X that blocked the cell cycle.

Use the following information for questions 13-17:

In a transformation experiment, a sample of E. coli bacteria was mixed with a plasmid containing the gene for resistance to the antibiotic ampicillin (amp^r). Plasmid was not added to a second sample. Samples were plated on nutrient agar plates, some of which were supplemented with the antibiotic ampicillin. The results of E. coli growth are summarized below. The shaded area represents extensive growth of bacteria; dots represent individual colonies of bacteria.



13. Plates that have only ampicillin-resistant bacteria growing include which of the following?
    a. I only
    b. III only
    c. IV only
    d. I and II

14. Which of the following best explains why there is no growth on plate II?
    a. The initial E. coli culture was not ampicillin- resistant.
    b. The transformation procedure killed the bacteria.
    c. Nutrient agar inhibits E. coli growth.
    d. The bacteria on the plate were transformed.

15. Plates I and III were included in the experimental design in order to
    a. demonstrate that the E. coli cultures were viable
    b. demonstrate that the plasmid can lose its amp^r gene
    c. demonstrate that the plasmid is needed for E. coli growth
    d. prepare the E. coli for transformation

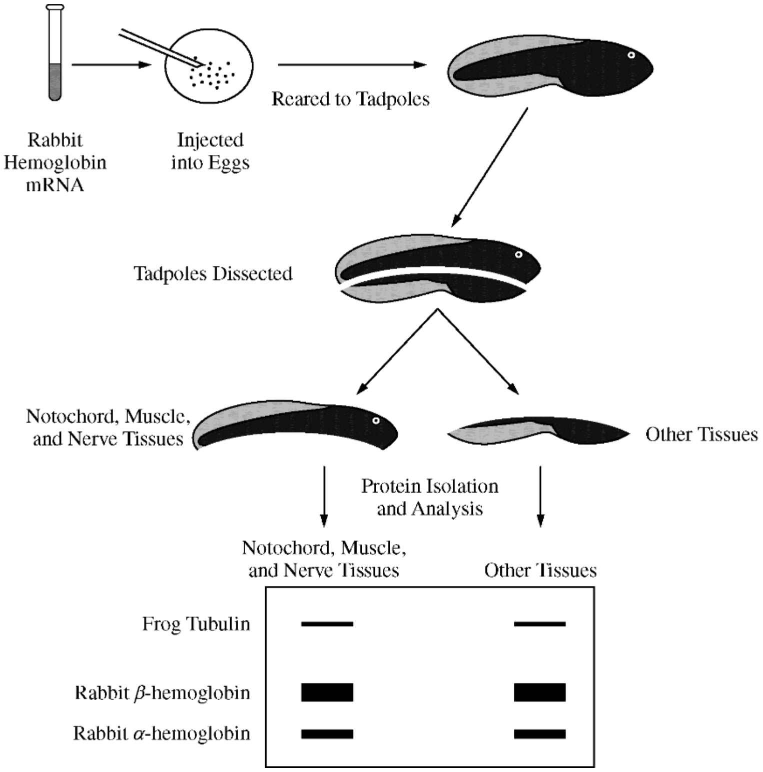
16. Which of the following statements best explains why there are fewer colonies on plate IV than on plate III?
    a. Plate IV is the positive control.
    b. Not all E. coli cells are successfully transformed.
    c. The bacteria on plate III did not mutate.
    d. The plasmid inhibits E. coli growth.

17. In a second experiment, the plasmid contained the gene for human insulin as well as the amp^r gene. Which of the following plates would have the highest percentage of bacteria that are expected to produce insulin?
    a. I only
    b. III only
    c. IV only
    d. I and III

Use the following information for questions 18-21:

In a classic experiment from the 1970s investigating gene expression, a solution containing equal amounts of rabbit a-hemoglobin mRNA and b-hemoglobin mRNA, which encode subunits of a protein found in red blood cells, was injected into newly fertilized frog eggs. The injected mRNA was not degraded during the course of the experiment. Tadpoles that developed from the injected eggs were dissected into two fragments, one containing predominantly the notochord, muscle tissue, and nerve tissue and the other containing predominantly the other tissue types.

Equal amounts of total protein were analyzed after separation by electrophoresis to identify the relative amounts of the different proteins present in each sample. The thickness of the bands indicates the relative amounts of rabbit α-hemoglobin, rabbit β-hemoglobin, and frog tubulin (a cytoskeletal protein that is expressed at relatively constant levels in all tissues) present in each tadpole sample. The experimental protocol and results are summarized in the figure below.



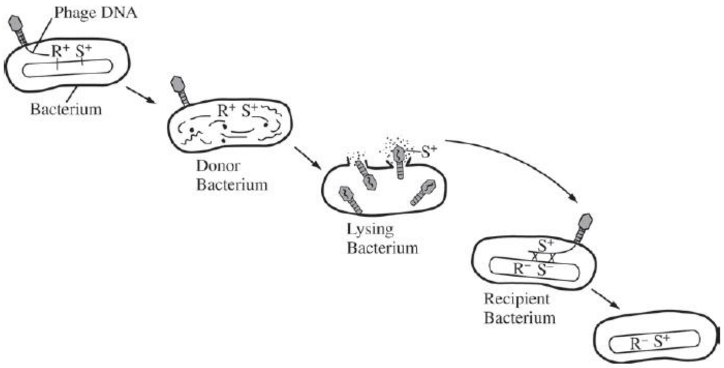
18. The observation that the rabbit mRNA was successfully translated in the frog tissues supports which of the following conclusions?
    a. Frog cells are able to replace their own hemoglobin with rabbit hemoglobin.
    b. Undeveloped frog eggs can be induced to form genetically identical copies of a rabbit.
    c. Rabbit hemoglobin can induce an immune response in frogs.
    d. Rabbits and frogs share a common genetic code for expressing heritable information.

19. The electrophoresis results best support which of the following conclusions?
    a. Cell specialization during development results in some cells losing the ability to synthesize proteins.
    b. Cells from different tissues share a common ability to use genetic material from a foreign source to produce protein.
    c. In comparison with other cells, nerve cells have a superior ability to produce cytoskeletal proteins.
    d. Muscle cells produce more β-hemoglobin than do cells from the other tissues in a tadpole.

20. Which of the following conclusions is most consistent with the results of the experiment?
    a. Rabbit mRNA is composed of nucleotides that are absent from frog mRNA.
    b. A larger volume of blood circulates through a rabbit than through a frog.
    c. The subunits of hemoglobin differ in size, shape, or charge.
    d. Synthesis of β-hemoglobin occurs at a faster rate in muscle cells than in other body cells.

21. Given that equal amounts of the different mRNAs were injected into fertilized frog eggs, which of the following conclusions is most consistent with the electrophoresis results?
    a. β-hemoglobin mRNA is translated more efficiently than is α-hemoglobin mRNA.
    b. α-hemoglobin is present only in cells where β-hemoglobin is absent.
    c. α-hemoglobin mRNA is more stable than β-hemoglobin mRNA.
    d. Tubulin inhibits translation of hemoglobin mRNA.

22. The figure below shows several steps in the process of bacteriophage transduction in bacteria. Which of the following explains how genetic variation in a population of bacteria results from this process?



    a. Bacterial proteins transferred from the donor bacterium by the phage to the recipient bacterium recombine with genes on the recipient's chromosome.
    b. The recipient bacterium incorporates the transduced genetic material coding for phage proteins into its chromosome and synthesizes the corresponding proteins.
    c. The phage infection of the recipient bacterium and the introduction of DNA carried by the phage cause increased random point mutations of the bacterial chromosome.
    d. DNA of the recipient bacterial chromosome undergoes recombination with DNA introduced by the phage from the donor bacterium, leading to a change in the recipient's genotype.

23. In 1944 Avery, MacLeod, and McCarty performed transformation experiments using live, harmless bacteria and extracts from virulent bacteria treated with various enzymes. Which of the following enzymes were used and why?
    a. Proteases and RNases to rule out protein and RNA as the transforming factors
    b. Lipase (an enzyme that facilitates the breakdown of lipids) to rule out lipoproteins as the transforming factor
    c. Kinase (an enzyme that facilitates transfer of a phosphate group from ATP to a substrate molecule) to show that transformation is phosphorylation dependent
    d. ATPase to show that transformation is not dependent on ATP

24. How does the DNA in a prokaryote differ from a eukaryote?
    a. Prokaryote has circular DNA, Eukaryotes has linear DNA
    b. Prokaryote has single stranded DNA, Eukaryotes has double stranded DNA
    c. Prokaryote has linear DNA, Eukaryotes has prokaryote DNA
    d. Prokaryote has double stranded DNA, Eukaryotes has single stranded DNA

25. Both eukaryotes and prokaryotes have plasmids. What are plasmids?
    a. large extra-chromosomal, double-stranded, linear DNA molecules
    b. large extra-chromosomal, double-stranded, circular DNA molecules
    c. small extra-chromosomal, double-stranded, circular DNA molecules
    d. small extra-chromosomal, double-stranded, linear DNA molecules

26. Identify which of the following best describes purines and pyrimidines.
    a. Purines (C, T, & U) have single ring, Pyrimidines (A & G) have double ring
    b. Purines (C, T, & U) have double ring, Pyrimidines (A & G) have single ring
    c. Purines (A & G) have single ring, Pyrimidines (C, T, & U) have double ring
    d. Purines (A & G) have double ring, Pyrimidines (C, T, & U) have single ring

27. Which of the following demonstrates base pairing rules to 5' - CAGGT - 3'
    a. 3' - TGGAC - 5'
    b. 3' - GTCCA - 5'
    c. 5' - GTCCA - 3'
    d. 5' - CAGGT - 3'

28. Which enzyme is responsible for relaxing supercoiling in front of the replication fork?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

29. Which enzyme is responsible for unwinding the DNA strands?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

30. Which enzyme is requires RNA primers to initiate DNA synthesis?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

31. Which enzyme is responsible for joining the fragments on the lagging strand?
    a. helicase
    b. DNA polymerase
    c. topoisomerase
    d. ligase

32. Describe the difference between the synthesis of the leading and lagging strands.
    a. directionality: leading = 3' -> 5', lagging = 5' -> 3'
    b. synthesis continuity: leading = discontinuous & lagging = continuous
    c. directionality: leading = 5' -> 3', lagging = 3' -> 5'
    d. synthesis continuity: leading = continuous & lagging = discontinuous

33. How do the three types of RNA work together?
    a. mRNA carries message, tRNA carries amino acids, and rRNA makes ribosome
    b. mRNA makes ribosomes, tRNA carries amino acids, and rRNA relays information
    c. mRNA carries amino acids, tRNA transfer message, and rRNA makes ribosome
    d. mRNA is made, tRNA holds the DNA in place, and rRNA removes the deoxyribose

34. Which of the following are NOT post-transcriptional modifications?
    a. 5' cap
    b. intron removal
    c. poly-A tail
    d. TATA box

35. During transcription, what is the relationship between DNA and RNA?
    a. Template DNA is the noncoding strand, RNA reads DNA in 3' -> 5' direction
    b. Template DNA is the coding strand, RNA reads DNA in 3' -> 5' direction
    c. Template DNA is the noncoding strand, RNA reads DNA in 5' -> 3' direction
    d. Template DNA is the coding strand, RNA reads DNA in 5' -> 3' direction

36. Where does translation take place in prokaryotes & eukaryotes?
    a. Prokaryotes - cytosol; Eukaryotes - cytosol or nucleus
    b. Prokaryotes - cytosol or rough ER; Eukaryotes - cytosol
    c. Prokaryotes - cytosol; Eukaryotes - cytosol or rough ER
    d. Prokaryotes - cytosol or nucleus; Eukaryotes – cytosol

37. What is the sequence of nucleotides on mRNA read in triplets called?
    a. anticodon
    b. codon
    c. triplet box
    d. wobble

38. How do retroviruses violate the central dogma?
    a. Retroviruses are responsible for using DNA to synthesize more viral RNA
    b. Retroviruses are pre-historic and existed prior to the central dogma
    c. Retroviruses use enzymes to make DNA from RNA & integrate into host DNA
    d. Retroviruses use host DNA to make viral RNA, then incorporate into host DNA

39. Which of the following describes epigenetic changes that affect gene expression?
    a. alternative RNA splicing
    b. post-transcriptional modification
    c. DNA methylation or histone acetylation
    d. operon inhibition

40. Identify which molecules bind to the promoter region
    a. Ligase
    b. Topoisomerase
    c. DNA polymerase
    d. RNA polymerase

41. Identify the primary source of genetic variation
    a. crossing over
    b. mutations
    c. random fertilization
    d. independent assortment

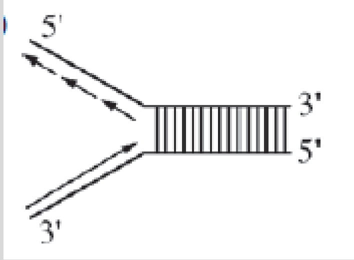
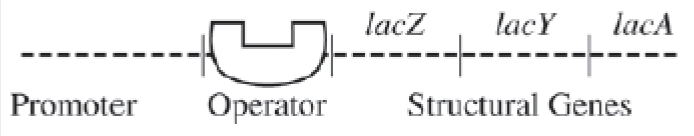
42. What determines the level of effect of a mutation?
    - a. environmental context
    - b. codon-anticodon pairing
    - c. structure of protein
    - d. process of meiosis

43. Which of the following is NOT a process of horizontal acquisition of genetic information by prokaryotes?
    - a. transformation
    - b. transposition
    - c. transduction
    - d. transjugation
    - e. plasmation

44. Which of the following genetic engineering techniques is incorrectly described?
    - a. Electrophoresis separates molecules based on size & charge
    - b. Bacterial transformation introduces DNA to bacterial cells
    - c. PCR allows for DNA fragments to be stabilized for engineering processes
    - d. DNA sequencing determines the order of nucleotides in a DNA molecule

45. Which of the following does NOT support the concept of common ancestry for all organisms?
    - a. DNA/RNA (genetic code) are shared by all living systems
    - b. Ribosomes are found in all forms of life
    - c. Glycolysis takes place in all organisms
    - d. All organisms undergo sexual reproduction

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	D. 	6.2	2012 CED #3
2	B. Different exons are retained or spliced out of the primary transcript.	6.3	2020 CED #11
3	A. Bicoid protein inhibits translation of caudal mRNA.	6.4*	2012 CED #19
4	D. 5' CUG ACU CCU GUG GAG AAG UCU 3'	6.4*	2013 #49
5	A. The HbA DNA contains a recognition site for the Mst II restriction enzyme.	6.8*	2013 #50
6	C. The activator is a sequence-specific DNA-binding protein that is present in some tissues but not in other tissues.	6.5	2013 #38
7	D.  lacZ lacY lacA Promoter Operator Structural Genes	6.5	2012 CED #7
8	D. Do mutations in the POU4F3 gene affect MYO6 mRNA levels in cells?	6.6	2020 CED #3
9	A. properties of the molecule as a result of abnormal interactions between adjacent hemoglobin molecules	6.7	2012 CED #20
10	B. How does the disrupted chloride movement affect the movement of sodium ions and water by the cell?	2.5	2013 #26
11	B. An increase in genetic variation	6.7	2013 #15
12	A. Protein X normally stimulates cell division, and the mutation created an overactive version of protein X.	6.7	2013 #25
13	C. IV only	6.8	2012 CED #24
14	A. The initial E. coli culture was not ampicillin- resistant.	6.8	2012 CED #25
15	A. demonstrate that the E. coli cultures were viable	6.8	2012 CED #26
16	B. Not all E. coli cells are successfully transformed.	6.8	2012 CED #27
17	C. IV only	6.8	2012 CED #28
18	D. Rabbits and frogs share a common genetic code for expressing heritable information.	6.4*	2013 #27

19	B. Cells from different tissues share a common ability to use genetic material from a foreign source to produce protein.	6.8*	2013 #26
20	C. The subunits of hemoglobin differ in size, shape, or charge.	6.8*	2013 #30
21	A. β-hemoglobin mRNA is translated more efficiently than is α-hemoglobin mRNA.	6.8*	2013 #31
22	D. DNA of the recipient bacterial chromosome undergoes recombination with DNA introduced by the phage from the donor bacterium, leading to a change in the recipient's genotype.	6.7*	2012 CED #39
23	A. Proteases and RNases to rule out protein and RNA as the transforming factors	*	2013 #9
24	A. Prokaryote has circular DNA, Eukaryotes has linear DNA	6.1	Self
25	C. small extra-chromosomal, double-stranded, circular DNA molecules	6.1	Self
26	D. Purines (A & G) have double ring, Pyrimidines (C, T, & U) have single ring	6.1	Self
27	B. 3' - GTCCA - 5'	6.1	Self
28	C. topoisomerase	6.2	Self
29	A. helicase	6.2	Self
30	B. DNA polymerase	6.2	Self
31	D. ligase	6.2	Self
32	D. synthesis continuity: leading = continuous & lagging = discontinuous	6.2	Self
33	A. mRNA carries message, tRNA carries amino acids, and rRNA makes ribosome	6.3	Self
34	D. TATA box	6.3	Self
35	A. Template DNA is the noncoding strand, RNA reads DNA in 3' -> 5' direction	6.3	Self
36	C. Prokaryotes - cytosol; Eukaryotes - cytosol or rough ER	6.4	Self
37	B. codon	6.4	Self
38	C. Retroviruses use enzymes to make DNA from RNA & integrate into host DNA	6.4	Self
39	C. DNA methylation or histone acetylation	6.5	Self
40	D. RNA polymerase	6.6	Self
41	B. mutations	6.7	Self
42	A. environmental context	6.7	Self
43	E. plasmation	6.7	Self
44	C. PCR allows for DNA fragments to be stabilized for engineering processes	6.8	Self
45	D. All organisms undergo sexual reproduction	2.1/3.3/6.4	Self

Multiple Choice Explanations

Q		Explanation:
1	A	The top strand here is read 5’ to 3’ and being made 3’ to 5’ which is opposite of the directionality of DNA replication. This option is incorrect. The figure shows both template strands of DNA being replicated continuously in a parallel direction. No “lagging” strand with Okazaki fragments is identified. DNA polymerase’s structure does not allow it to add nucleotides in the 5' direction. (CollegeBoard)
	B	The top strand here is read 5’ to 3’ and being made 3’ to 5’ which is opposite of the directionality of DNA replication. This option is incorrect. The figure incorrectly shows Okazaki fragments on the “leading” strand and both new strands being assembled in a parallel direction. DNA polymerase’s structure does not allow it to add nucleotides in the 5' direction. (CollegeBoard)
	C	The top strand here is read 5’ to 3’ and the bottom strand is read 5’ to 3’ so both strands are being made 3’ to 5’ which is opposite of the directionality of DNA replication. This option is incorrect. The figure incorrectly shows both strands being replicated continuously, and no Okazaki fragments on the lagging strand are identified. The new strands are shown being assembled in the 3'-to-5' direction, but the limitations of DNA polymerase only allow assembly in the 5'-to-3' direction. (CollegeBoard)
	D	**DNA reads 3’ to 5’ and DNA is made 5’ to 3’. In addition, there are two “types” of strands. The leading strand (bottom) is synthesized continuously towards the replication fork and the lagging strand is synthesized discontinuously away from the replication fork.** **This option is correct. It demonstrates an understanding of the structure of DNA and the process of replication. The two strands of the DNA molecule run antiparallel to each other; the 5' end of one strand pairs with the 3' end of the other strand. Replication is semi-conservative, with each strand serving as the template for the creation of new complementary strands. Helicase unzips the DNA molecules between the hydrogen bonds connecting the two strands. DNA polymerase “reads” each template strand in the 3'-to-5' direction and assembles the growing DNA chain in a 5'-to-3' direction. The “leading” strand is produced continuously, but on the “lagging” strand, Okazaki fragments are produced and are connected by ligase to produce the daughter molecule.**
2	A	Introns are non-coding regions of the DNA.
	B	**The exons are the coding regions of the DNA. If the same exons were spliced then same polypeptide would be formed.**
	C	The 5’ (GTP) cap allows for the mRNA to exit the nucleus and it aids in the binding of the ribosome to the 5’ end of the mRNA for translation.
	D	The primary transcript needs to be read as mRNA in order to be a template for the polypeptide synthesis.
3	A	**If you look at the second figure, you will see the slow decrease of bicoid is complemented by the slow increase of caudal. This shows that there is a negative relationship between the two whereas the bicoid inhibits the synthesis of the caudal protein.**

		This option is correct. The second indicatesthat, after fertilization, the concentration of the bicoid protein decreases asthe concentration of the caudal protein increases. Inhibition of the translation of caudal protein by bicoid protein is a logical hypothesis about the interaction of these two proteins and supports the concept that both the coordination and timing of these two proteins are necessary for the normal development in a Drosophila egg. (CollegeBoard)
	B	If the bicoid stabilized the caudal, the bicoid will have a similar trend (both high or both low) This option is incorrect. There is no indication that the bicoid protein stabilizes caudal DNA. The first graph shows the relative concentrations of mRNA for the two proteins; the second shows the relative concentration of the proteins.
	C	As the bicoid mRNA decreases, the caudal mRNA remains at high concentrations. (CollegeBoard) This option is incorrect. There are not enough data to support that translation of bicoid mRNA produces caudal protein. (CollegeBoard)
	D	According to the figure, caudal protein has a higher concentration in the posterior demonstrating that it stimulates the development of the posterior structures. This option is incorrect. The second graph shows that caudal protein stimulates the development of posterior structures, not anterior structures, as indicated in the graph. (CollegeBoard)
4	A	DNA is read 3' to 5'. This answer choice uses the non-template strand to base pair for the mRNA.
	B	DNA is read 3' to 5'. This answer choice uses the template strand (correct) but reads in the wrong direction. In addition, this does not follow the antiparallel directionality of DNA.
	C	This answer choice uses the non-template strand to base pair for the mRNA.
	D	**The template strand is read (3' to 5'):** 3' GAC TGA GGA CTC CTC TTC AGA 5' **To make mRNA, base pair:** 5' CUG ACU CCU GAG GAG AAG UCU 3' **GAG codes for Glu while GUG codes for Val**
5	A	**Based on the pedigree, Individual I is HbS HbS, individual II is HbA HbS, and individual HbA HbA. Based on the gel electrophoresis, there is ONE restriction site since there are two fragments.**
	B	Individual II is HbA/HbS. It has TWO restriction sites since there are three fragments.
	C	The one band represents that there were no restriction sites for the restriction enzyme to cut the DNA into smaller fragments.
	D	HbS/HbA has two alleles – HbA and HbS. The three fragments is due to the restriction enzyme having two restriction sites.
6	A	This does not compare the liver cells to other cells.
	B	If the activation is inhibited in liver cells, then the liver cell would not synthesize the protein. Based on the prompt, the liver cells express the gene while nerve cells do not.
	C	**As seen in the figure, the activator binds to the enhancer region causing the DNA to bend to create a secure binding region for RNA polymerase. If this activator does not bind to the enhancer, the DNA would not bend over and there would be a decrease in transcription and thus a decrease in translation. Each cell has different activators which explains why it is expressed in liver cells and not in nerve cells.**
	D	DNA is identical in all cells. This region would be found in the DNA of liver cells and DNA in nerve cells.
7	A	When lactose is present, it binds with the repressor protein to deactivate it. Since the repressor does not bind to the operator, the operon is on. This will synthesize the proteins needed to break down lactose.

		This option is incorrect because lactose has bonded with the repressor protein, resulting in its release from the operator. This will allow RNA polymerase to transcribe the lac operon because the molecular barrier no longer exists. (CollegeBoard)
	B	If lactose is bound to the repressor, the repressor is no longer bound to the operator. This option is incorrect because if lactose did bind with the repressor protein, then it would result in a conformational change and the repressor protein would no longer bind to the operator portion of the operon. No transcription would occur. (CollegeBoard)
	C	The prompt states that lactose is NOT being utilized. The lac operon is an inducible operon, so the repressor should be bound to the operator. This option is incorrect because with no repressor in place, the operon would be turned on, and the genes would be transcribed (CollegeBoard)
	D	**The prompt states that lactose is NOT being utilized, which means that the lactose is not binding the repressor. Since the lactose is not being to the repressor, the repressor binds to the operator inhibiting the binding of RNA polymerase which inhibits the transcription of the structural genes.** **This option is correct because the lac operon is an inducible operon, which means that the regulatory system is turned off until lactose or its analog turns it on. The mechanism for preventing its transcription is the binding of a repressor protein to the operator region (CollegeBoard)**
8	A	The other genes are not what is being studied by the researchers.
	B	If we are investigating hearing loss, determining the mutations in other cells does not provide a solution to the investigated problem.
	C	The researchers are studying the affect in humans, so it is not necessary to determine the mutations in mice.
	D	**According to the prompt, "researchers… proposed that POU4F3 encodes a transcription factor that influences the regulation of MYO6". If this were true, a mutation in POU4F3 would encode a defective transcription factor which could affect the transcription of MYO6. If MYO6 is reduced, there could be a hearing loss and since it's found in the DNA (mutation), the trait can be inherited.**
9	A	**The missense mutation (one amino acid is substituted for another amino acid) causes a hydrophilic amino acid to be substituted with a hydrophobic amino acid. The prompt states this is located on the exterior of the protein. This would result in a confirmational shape change which will affect the function of the protein by "resulting in abnormal interactions".** **This option is correct. The mutation results in the replacement of an amino acid, which alters the properties of the R-group both structurally and functionally; thus, the interactions between adjacent hemoglobin molecules would also be altered. In this case, hemoglobin molecules would tend to stick together as a result of hydrophobic interactions between amino acids on the surface. (CollegeBoard)**
	B	The hydrogen bonding of the DNA is not affected by this mutation. The point mutation would replace both nitrogenous bases. This option is incorrect. A point mutation, which causes the replacement of an amino acid with another amino acid, has already occurred in the DNA. The replacement of one amino acid would not alter the hydrogen bonding between nitrogenous bases in the structure of DNA. (CollegeBoard)

	C	Proteins do not have a fatty acid. The phospholipids and fats have 2 and 3 fatty acids, respectively. This option is incorrect. A point mutation, which causes the replacement of a hydrophilic amino acid R-group with another amino acid that has a hydrophobic R-group, would not alter a fatty acid. (CollegeBoard)
	D	The secondary structure is a result of hydrogen bonding between the polypeptide backbone versus the missense mutation affects the R groups of the amino acids (which is tertiary structure) This option is incorrect. A mutation is not likely to alter the secondary structure of a protein. The secondary structure of proteins is due to hydrogen bonding between the carboxyl and amine residues in the chain, not interactions between R-groups (CollegeBoard)
10	A	Based on the image, it does not appear that the mucus moves across the membrane. The different appears to be in the hydrated vs dehydrated mucus outside the cell.
	B	**Cystic fibrosis affects the chloride channels. When the chloride is moved across the membrane, the mucus is hydrated (water follows the ions) while when the chloride does not cross the membrane, the mucus is dehydrated. The researchers need to investigate how the disrupted chloride movement affects the sodium ions and water.**
	C	This question will provide more information about why the chloride is unable to cross the membrane, but it does not provide information about the mucus.
	D	This question will provide more information about the mutation (and possibly why the chloride is unable to cross the membrane), but it does not provide information about the mucus.
11	A	Transcription is reading DNA to synthesize a mRNA molecule.
	B	**Crossing over increases genetic variation. Conjugation increases genetic variation. Fertilization increases genetic variation.**
	C	Crossing over involves exchanging genetic information, so there is no increase in chromosome number.
	D	Horizontal gene transfer is the process where genetic information is shared between organisms without mating. This is demonstrated during the process of conjugation, but not crossing over or fertilization.
12	A	**If protein X stimulates cell division and protein X is overactive, protein X will continue to stimulate cell division excessively. This increase in cell division will result in a tumor (mass of cells).**
	B	If protein X activates a growth hormone receptor, it will be responsible for increased cell division BUT if the mutation decreases the stability, then there will be a decrease in cell division as the protein does not activate the receptor.
	C	If protein X inhibits cell division and protein X is overactive, it will continue to inhibit cell division resulting in less cell division.
	D	If protein X regulates gene expression and an underactive version of protein x, the cell cycle will be blocked resulting in less cell division.
13	A	Plate I is wild-type *E. coli* which is not ampicillin-resistant. This option is incorrect. Plate I shows an extensive growth of bacteria, which is normal when wild-type E. coli is grown without ampicillin. There was no selection for ampicillin resistance; thus, this plate served as a control. (CollegeBoard)
	B	Plate III is transformed *E. coli* which is ampicillin-resistant, but there is no ampicillin in the plate medium to restrict growth to ONLY ampicillin-resistant bacteria.

		This option is incorrect. Plate III shows E. coli and the ampicillin-resistant plasmid growing extensively when no ampicillin is present. Indication of which bacteria took up the naked DNA with the ampr gene is undetermined. (CollegeBoard)
	C	**Plate IV is transformed *E. coli* which is ampicillin-resistant and there is ampicillin in the plate medium which restricts growth to ONLY ampicillin-resistant bacteria.** This option is correct. Plate IV shows that only E. coli with the plasmid containing the gene for ampicillin-resistant plasmid grew individual colonies with ampicillin in the agar, thus showing the competent cells that transformed successfully. (CollegeBoard)
	D	Plate I and II is wild-type *E. coli* which is not ampicillin-resistant. This option is incorrect. Plate II shows that there is no bacterial growth when ampicillin is present; thus, there are no ampicillin-resistant bacteria (CollegeBoard)
14	A	**Plate II is wild-type *E. coli* which is not ampicillin-resistant BUT there is ampicillin in the plate medium which will inhibit growth of bacteria.** **This option is correct. The initial wild-type E. coli did not contain the plasmid containing the gene for resistance to the ampicillin (*amp*^{r}) and, when exposed to ampicillin, did not grow on Plate II. (CollegeBoard)**
	B	Based on the growth in plate I, the bacteria was viable and not affected by the transformation procedure. This option is incorrect. In a typical transformation experiment, if all procedures were followed as in this experiment, it is unlikely for a procedure to kill the bacteria. Plate IV indicates that the transformation procedure did not kill the bacteria (CollegeBoard)
	C	Based on the growth in plate I and III, the nutrient agar does not inhibit *E. coli* growth. This option is incorrect. Nutrient agar promotes E. coli growth (CollegeBoard)
	D	If the bacteria were transformed, they would have *amp* plasmid and be ampicillin resistant. This option is incorrect. The bacteria in Plate II were not exposed to the plasmid and thus could not have been transformed (CollegeBoard)
15	A	**Plate I and III have no ampicillin in the plate medium and have a lawn of growth. This demonstrates that the bacteria were viable and unharmed by the transformation process.** **This option is correct. Both PlatesI and III had extensive E. coli growth, showing that the cells were viable before and after the transformation procedure (CollegeBoard)**
	B	Plate I was not given the *amp* plasmid. This option is incorrect. Plates I and III would not have provided information on whether the plasmid could lose its *amp*^{r} gene, and there was no way of knowing this with the data from these two plates. (CollegeBoard)
	C	Plate I and III both have a lawn of growth and look identical. The presence of plasmid did not affect the growth of *E. coli* on the nutrient broth plates. This option is incorrect. The bacteria in Plate I were not exposed to the plasmid. (CollegeBoard)

	D	Plate III has already been transformed. This option is incorrect. The bacteria were plated after the transformation; thus, plating could not have prepared them for transformation. (CollegeBoard)
16	A	A positive control is a group in an experiment that receives a treatment that is known to produce results similar to those predicted by your hypothesis. Plate II is the positive control as the non-transformed bacteria should not grow in the presence of the ampicillin. This option is incorrect. Plate I is the positive control, showing that the bacteria were viable before the transformation procedure (CollegeBoard)
	B	**Plate III does not have ampicillin while Plate IV has ampicillin. The ampicillin will restrict the growth to ONLY ampicillin-resistant bacteria. Those *E. coli* that were not transformed** **This option is correct. Only the E. coli that have been transformed and contain the *amp*^{r} gene will grow and produce colonies. (CollegeBoard)**
	C	The experiment is not investigating mutations. This option is incorrect. The transformation experiment did not determine whether E. coli bacteria could mutate or not. (CollegeBoard)
	D	The plasmid provides the ampicillin resistance and does not inhibit *E. coli* growth. This option is incorrect. Both plates with plasmids showed growth while the plate with ampicillin and no plasmids showed no growth, indicating that plasmids did not inhibit growth. (CollegeBoard)
17	A	Plate I is wild-type *E. coli* which does not have the plasmid and cannot synthesize insulin. This option is incorrect. The bacteria in Plate I were not exposed to the plasmid. (CollegeBoard)
	B	Plate III is transformed *E. coli* and can synthesize insulin (and is ampicillin resistant), but there is no ampicillin in the plate medium to restrict growth to ONLY ampicillin-resistant bacteria so this will not have the highest percentage of bacteria able to produce insulin. This option is incorrect. Plate III does not distinguish which bacteria took up the plasmid. Bacteria with and without the plasmid grow, but the percentage of those with the ability to produce insulin is much lower than in Plate IV. (CollegeBoard)
	C	**Plate IV is transformed *E. coli* and can synthesize insulin (and is ampicillin resistant), and there is ampicillin in the plate medium which restricts growth to ONLY ampicillin-resistant bacteria so 100% of the bacteria can produce insulin.** **This option is correct. In Plate IV the colonies of E. coli were successfully transformed and expressed the *amp*^{r} gene; adding another gene to the plasmid would express the human insulin gene the same way. (CollegeBoard)**
	D	Plate I and II is wild-type *E. coli* which does not have the plasmid and cannot synthesize insulin. This option is incorrect. The bacteria on Plate I were not exposed to the plasmid and so could not have taken up the insulin gene, thus eliminating this choice. (CollegeBoard)
	A	This is discussing that the frog replaces their hemoglobin with the rabbit hemoglobin but the frog still has its own mRNA for the frog hemoglobin,

18	B	The researchers only injected hemoglobin mRNA.
	C	How does an immune response explain the frog making a rabbit protein?
	D	**The question is asking how was the frog tissues able to translate the rabbit mRNA. This is a homology that all organisms share their genetic code. You are able to place the mRNA into another organism to be translated.**
19	A	Both gels look the same demonstrating that there was no difference between the notochord, muscle, and nerve compared to other tissues. All cells synthesize the protein equally.
	B	**The cells from the notochord, muscle, nerve, and other tissues are able to use the rabbit mRNA to synthesize the two forms of hemoglobin demonstrating that cells of different tissues can use genetic material from a foreign source to produce protein.**
	C	Nerve cells have the same amount of tubulin as other cells based on the data from the gel.
	D	Muscle cells have the same amount of β-hemoglobin as other cells based on the data from the gel.
20	A	The mRNA nucleotides used is not able to be determined from a gel electrophoresis.
	B	The volume of blood has no affect on the proteins ran through the gel electrophoresis.
	C	**The function of a gel electrophoresis separates materials based on size, shape, or charge. Since there are three bands, this demonstrates there is a difference between the proteins with one of these characteristics.**
	D	The rate of synthesis is not able to be determined from a gel electrophoresis.
21	A	**There is more β-hemoglobin than α-hemoglobin as represented by the thicker band with β-hemoglobin. Since the same amount of mRNA was injected, the β-hemoglobin must have been translated more efficiently.**
	B	Both α-hemoglobin and β-hemoglobin is present in the cells based on the gel.
	C	More stable mRNA would remain in the cytosol longer and be translated more yielding a higher concentration. There is more β-hemoglobin and less α-hemoglobin which does not fit this statement.
	D	If tubulin inhibited the translation, there would be no hemoglobin found in the cells.
22	A	As determined with the Hershey and Chase experiment, the proteins from the bacteriophage remain outside the bacteria. In addition, protein will not recombine with DNA. This option is incorrect because bacterial DNA, not protein, is transferred by the phage (CollegeBoard)
	B	This response feels correct, but it also feels like it is not detailed enough. How does transduced genetic material get incorporated into the bacteria DNA. This option is incorrect because the recipient does not incorporate (add) the transduced DNA into its chromosome. The transduced DNA must recombine with the recipient DNA in order to become part of the chromosome (CollegeBoard)
	C	Random point mutations would not explain why the gene from the bacteriophage is now incorporated in the bacteria DNA. This option is incorrect because recombinant DNA does not cause point mutations (CollegeBoard)
	D	**Recombination involves when DNA from two different sources is incorporated together within one strand of DNA (traditionally discussed with crossing over). As seen in the diagram (4th bacteria image), there is crossing over taking place between the bacteriophage DNA and the bacteria DNA. The S^+ from the bacteriophage gets incorporated into the bacteria DNA and the S^- from the bacteria gets incorporated into the bacteriophage DNA. This causes the bacteria to have a change in genotype from R^-S^- to R^-S^+.**

		This option is correct. Transduction is the transfer of bacterial genes from one bacterium to another by bacteriophages (CollegeBoard)
23	A	**Proteases digests proteins. RNases digest RNA. The sample had DNA, RNA, and proteins. These enzymes remove the RNA and proteins to leave over DNA to determine if it was the transforming agent.**
	B	If you digest the lipids on the lipoproteins, there is still RNA and DNA in the sample. The scientists are unable to determine which is the transforming agent.
	C	If you add kinase, it will allow for phosphorylation of the substrate but how does this help you to determine the transforming agent?
	D	ATPase will synthesize dephosphorylate ADP to synthesize ATP. Again, how does this help you to determine the transforming agent?
24	A	**Genetic information is transmitted from one generation to the next through DNA or RNA—(b) Prokaryotic organisms typically have circular chromosomes, while eukaryotic organisms typically have multiple linear chromosomes. (IST-1.K.2)**
	B	DNA is double stranded in both organisms.
	C	This statement is backwards. Prokaryotes have circular DNA and eukaryotes have linear DNA.
	D	DNA is double stranded in both organisms.
25	A	Plasmids are not large extra-chromosomal nor linear DNA
	B	Plasmids are not large extra-chromosomal DNA
	C	**Prokaryotes and eukaryotes can contain plasmids, which are small extra-chromosomal, double-stranded, circular DNA molecules (IST-1.K.3)**
	D	Plasmids are not linear DNA
26	A	C, T, & U are pyrimidines and A & G are purines
	B	C, T, & U are pyrimidines and A & G are purines
	C	Purines have a double ring and pyrimidines have a single ring
	D	**DNA, and sometimes RNA, exhibits specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G)—(a) Purines (G and A) have a double ring structure. (b) Pyrimidines (C, T, and U) have a single ring structure. (IST-1.L.1)**
27	A	This does not follow base pairing rules. G & C and A & T will pair together in DNA.
	B	**DNA, and sometimes RNA, exhibits specific nucleotide base pairing that is conserved through evolution: adenine pairs with thymine or uracil (A-T or A-U) and cytosine pairs with guanine (C-G) (IST-1.L.1)** **5' - CAGGT - 3'** **3' – GTCCA – 5'**
	C	This follows base pairing rules but does not demonstrate the antiparallel nature of DNA.
	D	This is the same strand as the template.
28	A	Helicase unwinds the DNA strands. (IST-1.M.1c)
	B	DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)
	C	**Topoisomerase relaxes supercoiling in front of the replication fork. (IST-1.M.1d)**
	D	Ligase joins the fragments on the lagging strand. (IST-1.M.1g)
29	A	**Helicase unwinds the DNA strands. (IST-1.M.1c)**
	B	DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)
	C	Topoisomerase relaxes supercoiling in front of the replication fork. (IST-1.M.1d)

	D	Ligase joins the fragments on the lagging strand. (IST-1.M.1g)
30	A	Helicase unwinds the DNA strands. (IST-1.M.1c)
	B	**DNA polymerase requires RNA primers to initiate DNA synthesis. (IST-1.M.1e)**
	C	Topoisomerase relaxes supercoiling in front of the replication fork. (IST-1.M.1d)
	D	Ligase joins the fragments on the lagging strand. (IST-1.M.1g)
31	A	Helicase unwinds the DNA strands. (IST-1.M.1c)
	B	DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)
	C	Topoisomerase relaxes supercoiling in front of the replication fork. (IST-1.M.1d)
	D	**Ligase joins the fragments on the lagging strand. (IST-1.M.1g)**
32	A	DNA is synthesized in the 5' to 3' direction. (IST-1.M.1a). Both leading and lagging strands are synthesized 5' to 3'.
	B	DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)
	C	DNA is synthesized in the 5' to 3' direction. (IST-1.M.1a). Both leading and lagging strands are synthesized 5' to 3'.
	D	**DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)**
33	A	**The sequence of the RNA bases, together with the structure of the RNA molecule, determines RNA function—(a) mRNA molecules carry information from DNA to the ribosome. (b) Distinct tRNA molecules bind specific amino acids and have anti-codon sequences that base pair with the mRNA. tRNA is recruited to the ribosome during translation to generate the primary peptide sequence based on the mRNA sequence. (c) rRNA molecules are functional building blocks of ribosomes (IST-1.N.1)**
	B	rRNA makes ribosomes and mRNA carries the message
	C	tRNA carries amino acids, mRNA carries the message
	D	mRNA carries message, tRNA transfers amino acids, and rRNA makes up the ribosome
34	A	In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications—(a) Addition of a poly-A tail. (b) Addition of a GTP cap. (c) Excision of introns and splicing and retention of exons. (d) Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing. (IST-1.N.6)
	B	In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications—(a) Addition of a poly-A tail. (b) Addition of a GTP cap. (c) Excision of introns and splicing and retention of exons. (d) Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing. (IST-1.N.6)
	C	In eukaryotic cells the mRNA transcript undergoes a series of enzyme-regulated modifications—(a) Addition of a poly-A tail. (b) Addition of a GTP cap. (c) Excision of introns and splicing and retention of exons. (d) Excision of introns and splicing and retention of exons can generate different versions of the resulting mRNA molecule; this is known as alternative splicing. (IST-1.N.6)
	D	**The TATA box is located near the promoter to facilitate the initiation of transcription**
35	A	**The DNA strand acting as the template strand is also referred to as the noncoding strand, minus strand, or antisense strand. Selection of which DNA strand serves as the template strand depends on the gene being transcribed. (IST-1.N.4) The enzyme RNA polymerase synthesizes mRNA molecules in the 5' to 3' direction by reading the template DNA strand in the 3' to 5' direction (IST-1.N.5)**

	B	The coding strand has the same sequence as the mRNA aside from the U for T substitution found in RNA vs. DNA.
	C	The enzyme RNA polymerase synthesizes mRNA molecules in the 5' to 3' direction by reading the template DNA strand in the 3' to 5' direction (IST-1.N.5)
	D	The enzyme RNA polymerase synthesizes mRNA molecules in the 5' to 3' direction by reading the template DNA strand in the 3' to 5' direction (IST-1.N.5) The coding strand has the same sequence as the mRNA aside from the U for T substitution found in RNA vs. DNA.
36	A	Translation does not take place in the eukaryotic nucleus as ribosomes are found in the cytosol and rough ER.
	B	Prokaryotes do not have membrane bound organelles including the rough ER
	C	**Translation of the mRNA to generate a polypeptide occurs on ribosomes that are present in the cytoplasm of both prokaryotic and eukaryotic cells and on the rough endoplasmic reticulum of eukaryotic cells. (IST-1.O.1)**
	D	Prokaryotes do not have membrane bound organelles including the nucleus
37	A	The anticodon is found on the tRNA. It will base pair with the codon on the mRNA.
	B	**The salient features of translation include—(b) The sequence of nucleotides on the mRNA is read in triplets called codons. (IST-1.O.4)**
	C	This was a made-up term. You fell into my trap – Mwahahaha
	D	The wobble refers to the variability of the third nucleotide in the codon that can be any of the four nucleotides but still codes for the same amino acid.
38	A	This is still within the central dogma as the DNA is used to synthesize the RNA
	B	This does not answer the question. Even if something existed before the central dogma, if it violates it you should be able to tell me how it violates it.
	C	**Genetic information in retroviruses is a special case and has an alternate flow of information: from RNA to DNA, made possible by reverse transcriptase, an enzyme that copies the viral RNA genome into DNA. This DNA integrates into the host genome and becomes transcribed and translated for the assembly of new viral progeny. (IST-1.O.5) The central dogma is DNA → RNA → polypeptide**
	D	This is still within the central dogma as the DNA is used to synthesize the RNA
39	A	This is post-transcriptional processing and is not involved in epigenetics
	B	Post-transcriptional modification affects the mRNA after transcription while epigenetics affects the process of transcription.
	C	**Epigenetic changes can affect gene expression through reversible modifications of DNA or histones (IST-2.A.2)**
	D	Inhibiting the operons involves repressors not modifications to the DNA or histones
40	A	Ligase joins the fragments on the lagging strand. (IST-1.M.1g)
	B	Topoisomerase relaxes supercoiling in front of the replication fork. (IST-1.M.1d)
	C	DNA polymerase synthesizes new strands of DNA continuously on the leading strand and discontinuously on the lagging strand. (IST-1.M.1f)
	D	**Promoters are DNA sequences upstream of the transcription start site where RNA polymerase and transcription factors bind to initiate transcription. (IST-2.C.1)**
41	A	Crossing over involves exchanging genetic information which reshuffles already existing genetic variation.
	B	**Mutations are the primary source of genetic variation (IST-4.A.1b)**
	C	Random fertilization involves the randomness of sperm and egg fusing which reshuffles already existing genetic variation.
	D	Independent assortment involves the homologous pairs aligning on the metaphase plate during metaphase I. This reshuffles already existing genetic variation.

42	A	**Whether a mutation is detrimental, beneficial, or neutral depends on the environmental context. (IST-4.A.1a)**
	B	If there is a mutation, there will be a different codon-anticodon pair but that doesn't determine the level of effect
	C	The structure of the protein will be modified, but that doesn't determine the level of effect
	D	Meiosis? This is a process that makes gametes (4 haploid unique cells) and doesn't determine the level of effect
43	A	The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase variation. (IST-4.B.1a)
	B	The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase variation. (IST-4.B.1a)
	C	The horizontal acquisitions of genetic information primarily in prokaryotes via transformation (uptake of naked DNA), transduction (viral transmission of genetic information), conjugation (cell-to-cell transfer of DNA), and transposition (movement of DNA segments within and between DNA molecules) increase variation. (IST-4.B.1a)
	D	So… I made up this word when I made the review (combined conjugation and transformation/transduction), but apparently it is a real word that is a new type of horizontal gene transfer process in which a donor cell pushes out genomic DNA upon cell contact and a recipient cell pulls this DNA inside by natural transformation.
	E	**I know the transjuction is not in the standards, but I felt wrong keeping a correct answer and teaching you incorrect information. Plasmation means the act of forming or molding, so not anything to do with horizontal transfers.**
44	A	Electrophoresis separates molecules according to size and charge. (IST-1.P.1a)
	B	Bacterial transformation introduces DNA into bacterial cells. (IST-1.P.1c)
	C	**During polymerase chain reaction (PCR), DNA fragments are amplified. (IST-1.P.1b)**
	D	DNA sequencing determines the order of nucleotides in a DNA molecule (IST-1.P.1d)
45	A	Nearly all living organisms use the same genetic code, which is evidence for the common ancestry of all living organisms. (IST-1.O.4)
	B	Ribosomes are found in all forms of life, reflecting the common ancestry of all known life. (SYI-1.D.2)
	C	Glycolysis takes place in the cytosol and does not require oxygen, so it can and will take place in all organisms.
	D	**Not all organisms undergo sexual reproduction. An example is bacteria.**

Free Response Practice

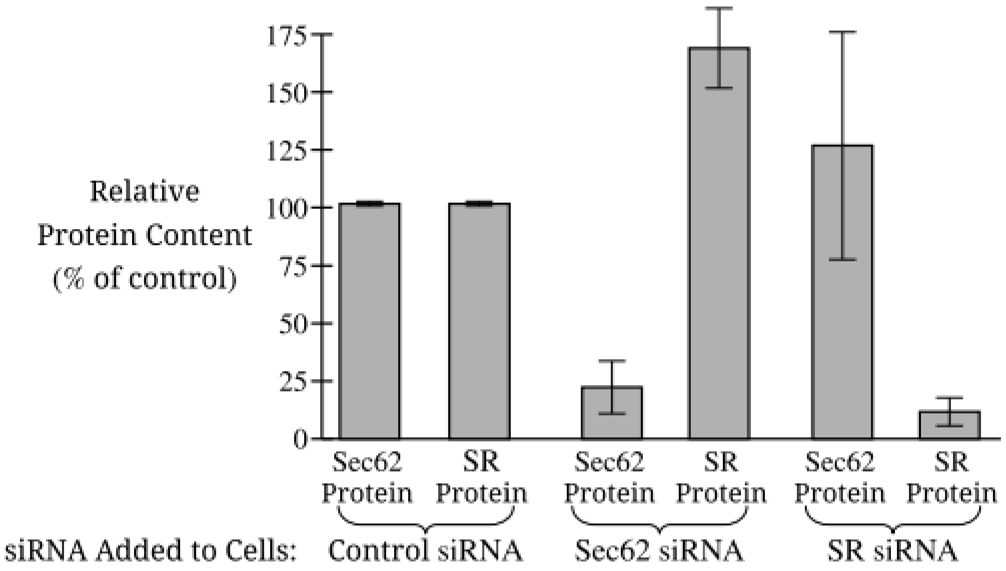
2025 #1

Most proteins that are secreted from a cell must be transported to the endoplasmic reticulum (ER) either during translation or after translation.

(a) **Describe** the function of ribosomes.

For proteins transported during translation, this process begins in the cytosol and pauses when a specific sequence of amino acids is translated. The translation complex is then transported to the surface of the ER where translation continues. Proteins that are transported after translation are translated entirely in the cytosol and then transported to the ER. In both instances, the translated proteins enter the ER through a protein channel in the membrane of the ER. Researchers studying the two types of protein transport identified that the ER membrane protein SR is necessary for transport during translation, while the ER membrane protein Sec62 is necessary for transport after translation. To investigate which transport mechanism is used for different proteins, researchers first created small interfering RNAs (siRNAs) that reduce expression of either SR or Sec62. They then treated groups of cells with either the SR siRNA or the Sec62 siRNA and determined the relative amount of SR and Sec62 protein in each group of cells compared with cells treated with a control siRNA (Figure 1).

Figure 1. Average relative amounts of Sec62 and SR proteins in cells treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent ±$SE_{\bar{x}}$.



(b)

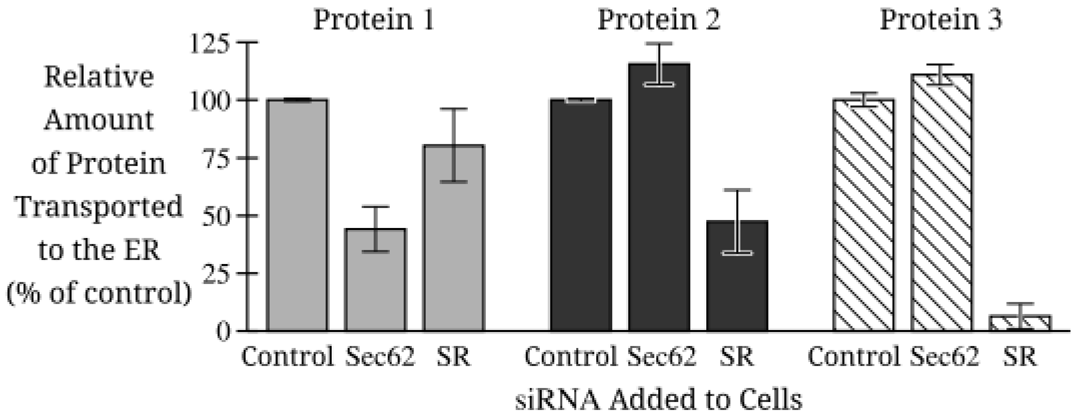
i. **Identify** the dependent variable in the experiments shown in Figure 1.

ii. **Justify** why the researchers included the control of measuring the relative amounts of both Sec62 and SR proteins in cells that were treated with Sec62 siRNA only (data shown in Figure 1).

iii. Based on Figure 1, **describe** the effect on the production of SR protein when cells are treated with Sec62 siRNA.

The researchers then measured the amount of each of three different proteins that was transported to the ER in cells treated with Sec62 siRNA or SR siRNA. The researchers calculated the percent transported relative to the cells treated with control siRNA (Figure 2).

Figure 2. Average relative amounts of three proteins that were transported to the ER when treated with control siRNA, Sec62 siRNA, or SR siRNA. Error bars represent $\pm SE_{\bar{x}}$.



(c)

i. **Identify** the independent variable in the researchers' second experiment (data shown in Figure 2).

ii. Based on Figure 2, **identify** the protein(s) that when treated with Sec62 siRNA showed an increase in percent transport to the ER compared with the control.

iii. Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, **calculate** the difference in the number of amino acids between the two proteins.

(d)

i. Researchers claim that protein 1 is the only tested protein that is transported to the ER following its complete translation in the cytosol. Using data from Figure 2, **support** the researchers' claim.

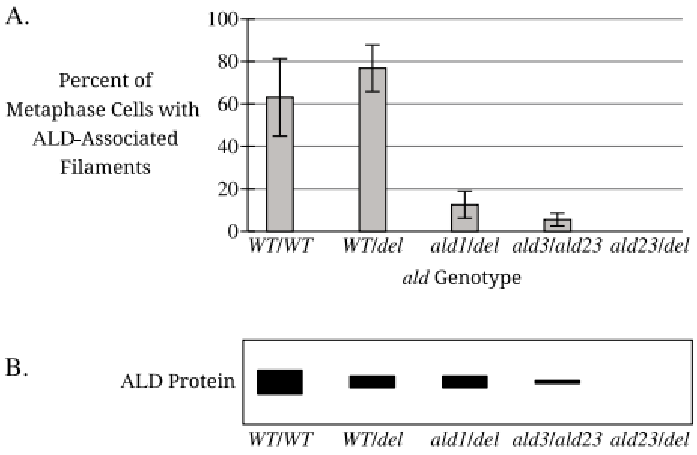
ii. For any protein that enters the ER, researchers claim that amino acids close to the protein's amino terminus determine how likely the protein is to pass through the protein channel within the ER membrane. **Justify** the researchers' claim based on your understanding of factors that affect the transport of proteins across membranes.

2025 #6

The *ald* gene of fruit flies encodes the ALD protein, which is associated with both the centromeres of chromosomes and protein filaments produced during meiosis. In the absence of functional ALD proteins, gamete-producing cells enter anaphase I before homologous chromosomes are correctly aligned. As a result, the gametes produced do not contain the correct numbers of chromosomes.

Scientists generated four mutations in the *ald* gene: *ald*1, *ald*3, *ald*23, and *del*, which was a deletion of the gene. To study the role of the ALD protein in meiosis, scientists used gameteforming metaphase cells from groups of flies with different *ald* genotypes. Some of the flies were homozygous for the wild-type allele of *ald*: WT/WT. Other flies were heterozygous for different *ald* alleles: WT/*del*; *ald*1/*del*; *ald*3/*ald*23; *ald*23/*del*. The scientists measured the percent of metaphase cells that contained ALD-associated filaments (Figure 1A) and the amount of ALD protein produced by each of the cell types (Figure 1B).

Figure 1. (A) The average percent of gamete-forming metaphase cells that contained filaments associated with ALD and (B) the amount of ALD protein produced by each cell type. A thicker band indicates a greater amount of ALD protein.



(a) Based on Figure 1A, **identify** the fly genotype in which the average percent of metaphase cells with ALD-associated filaments is close to 12%.

(b) Based on Figure 1B, **describe** the difference in ALD protein production between gamete forming metaphase cells of flies with the genotype *ald*3/*ald*23 and flies with the genotype *ald*23/del.

(c) Scientists hypothesize that gamete-forming metaphase cells can produce a normal amount of ALD-associated filaments even when they produce about half as much ALD protein as the wild-type cells produce. Use the data in Figures 1A and 1B to **support** the scientists' hypothesis.

(d) For gamete-forming metaphase cells of the WT/*del* and *ald*1/*del* flies, **explain** why the phenotypes observed in Figure 1A differ even though the amount of ALD protein produced (Figure 1B) does not.

2024 #6

Scientists can quantify the rate of translation as ribosomes move along an mRNA from one codon to the next. Using a procedure called ribosome profiling, the scientists measured how long a ribosome remains stationary at each codon of each mRNA. They determined the average translation rate across all codons is 5.2 amino acids per second but that the average translation rate for specific codons in different mRNA sequences can vary widely. These variations in translation rates are thought to facilitate correct folding of the protein being produced. The rate at which three different codons were translated was measured in 100 different mRNAs. The scientists determined the distribution of rate (number of times each rate was recorded) for each of the three codons: GAC (Figure 1A), AUU (Figure 1B), and UGG (Figure 1C).

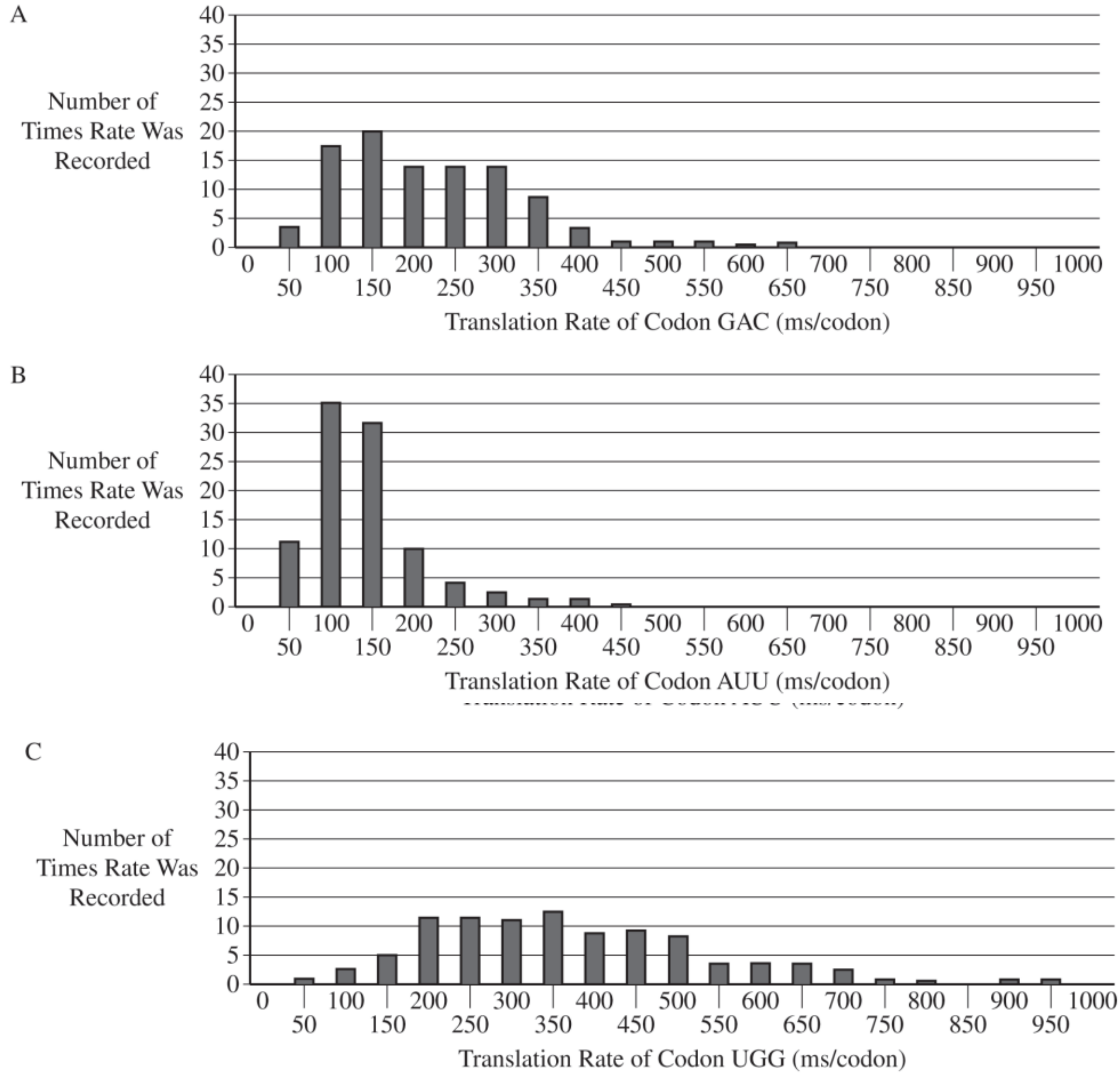


Figure 1. The distribution of translation rates for three different codons (A) GAC, (B) AUU, and (C) UGG

(a) Using the data in Figure 1, graph A, **identify** the rate (in ms/codon) that was recorded the greatest number of times for the GAC codon.

(b) Using the data in Figure 1, graphs B and C, **describe** the variation in translation rate of the AUU codon compared with that of the UGG codon.

(c) Scientists hypothesize that tRNA molecules that bind to UGG codons are available in lower abundance than are tRNAs that bind to AUU codons. **Support** the scientists' hypothesis using the data in Figure 1.

(d) Amino acids can be encoded by multiple codons. In many organisms, certain codons for the same amino acid occur more frequently in an mRNA than do other codons. Based on the data provided, **explain** why the use of one codon over another for the same amino acid might result in increased levels of protein production from a particular mRNA.

2023 #6

Housekeeping genes encode proteins involved in universally important processes such as transcription, translation, and glycolysis. Because these genes appear to be expressed in all cells at constant levels, the expression of housekeeping genes is often used as a control when comparing how the expression of other genes varies under different conditions.

Researchers studying the effect of pesticides on declining bee populations wanted to determine whether the expression of four housekeeping genes (GAPDH, RPL32, RPS5, and TBP-AF) was in fact constant in bees across different variables. The researchers collected samples of mRNA for each of the four genes and compared how their expression varied across the developmental stage of the bee, the sex of the bee, and the cell type from which the sample was taken. The mRNA from the samples was reverse transcribed to produce DNA copies of each gene. PCR was then used to amplify the DNA, and the Cq value was determined. The Cq value is the number of PCR cycles needed to produce a specified number of DNA copies. A high Cq value for a sample indicates the gene was expressed at a low level.

To analyze whether any of the examined variables affected expression of the housekeeping genes, researchers examined the range of Cq values for each gene in response to each variable. Genes with a wide range of Cq values were determined to be affected by the variable, while genes with a narrow range of values were determined to be unaffected by the variable.

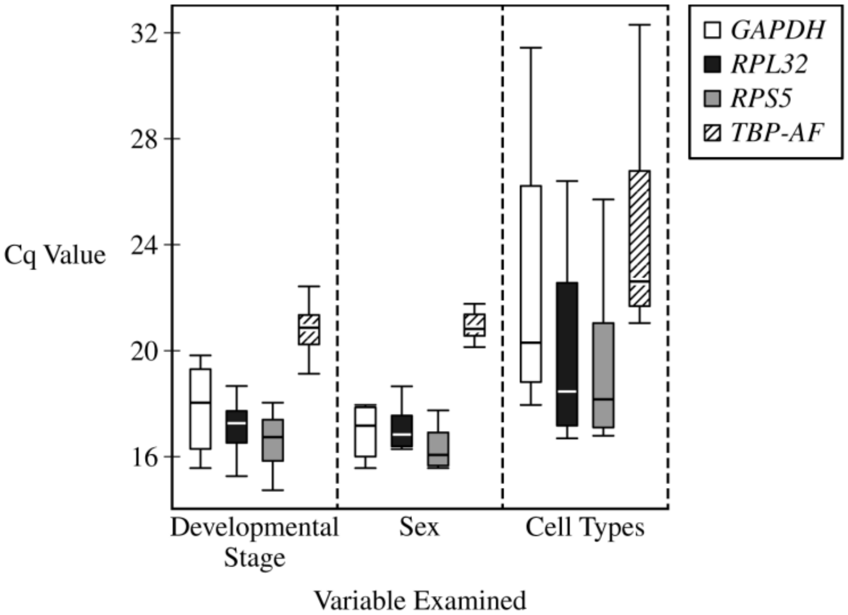


Figure 1. The effect of developmental stage, sex, and cell type on the Cq value of four housekeeping genes

(a) Based on the data in Figure 1, **identify** the gene that had the lowest median Cq value when bees of different developmental stages were compared.

(b) The Cq value is inversely proportional to the amount of mRNA from that gene in the starting sample. Based on the data in Figure 1, **identify** the gene that has the lowest level of gene expression regardless of variable.

(c) The scientists investigated the effect of pesticides on the expression of other genes in one cell type of a group of bees containing males and females of the same developmental stage. They hypothesized that TBP-AF would serve as the best control gene for this experiment. Use the data to **evaluate** their hypothesis.

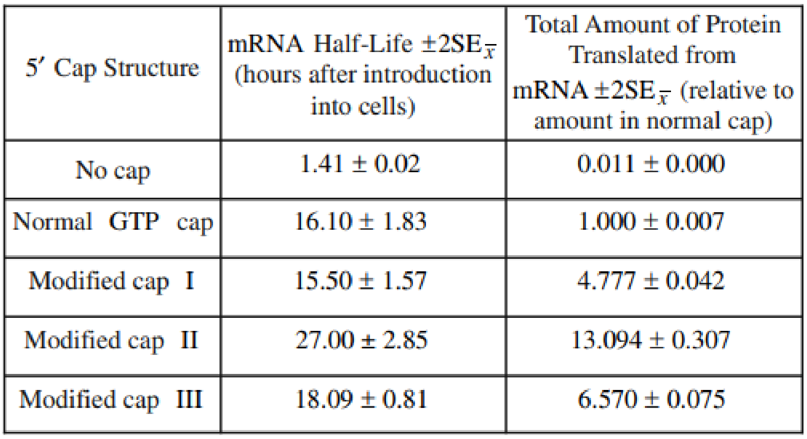
(d) **Explain** how expression of a gene such as GADPH can vary from one cell type to another within the same bee.

2022 #6

Researchers are studying the use of RNA vaccines to protect individuals against certain diseases. To develop the vaccines, particular cells are first removed from an individual. Then mRNAs coding for specific proteins from a pathogen are introduced into the cells. The altered cells are injected back into the individual, where the cells make the proteins encoded by the introduced mRNAs. The individual then produces an immune response to the proteins that will help to protect the individual from developing a disease if exposed to the pathogen in the future.

When introduced into cells, the mRNAs used for vaccines must be stable so that they are not degraded before the encoded proteins are produced. Researchers developed several modified caps that they hypothesized might make the introduced mRNAs more stable than mRNAs with the normal GTP cap. To test the effect of the modified caps, the researchers produced mRNAs that differed only in their cap structure (no cap, the normal cap, or modified caps I, II, or III). They introduced the same amount of each mRNA to different groups of cells and measured the amount of time required for half of the mRNAs to degrade (mRNA half-life) and the total amount of protein translated from the mRNAs (Table 1).

TABLE 1. EFFECT OF mRNA CAP STRUCTURE ON mRNA HALF-LIFE AND PROTEIN TRANSLATED FROM THE INTRODUCED mRNA



5′ Cap Structure	mRNA Half-Life ±2SE$_{\bar{x}}$ (hours after introduction into cells)	Total Amount of Protein Translated from mRNA ±2SE$_{\bar{x}}$ (relative to amount in normal cap)
No cap	1.41 ± 0.02	0.011 ± 0.000
Normal GTP cap	16.10 ± 1.83	1.000 ± 0.007
Modified cap I	15.50 ± 1.57	4.777 ± 0.042
Modified cap II	27.00 ± 2.85	13.094 ± 0.307
Modified cap III	18.09 ± 0.81	6.570 ± 0.075

(a) Based on the data, **identify** which cap structure is most likely to protect the end of the mRNAs from degradation.

(b) Based on the data for the mRNAs with modified caps, **describe** the relationship between the mRNA half-life and the total amount of protein produced.

(c) After examining the data on mRNA half-lives and the amount of protein produced, the researchers hypothesized that each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap. **Evaluate** their hypothesis by comparing the data in Table 1.

(d) Introduction of mRNAs into cells allows the cells to produce foreign proteins that they might not normally produce. **Explain** why the production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells.

2021 #2

Geneticists investigated the mode of inheritance of a rare disorder that alters glucose metabolism and first shows symptoms in adulthood. The geneticists studied a family in which some individuals of generations II and III are known to have the disorder. Based on the pedigree (Figure 1), the geneticists concluded that the disorder arose in individuals II-2 and was caused by a mutation in mitochondrial DNA.

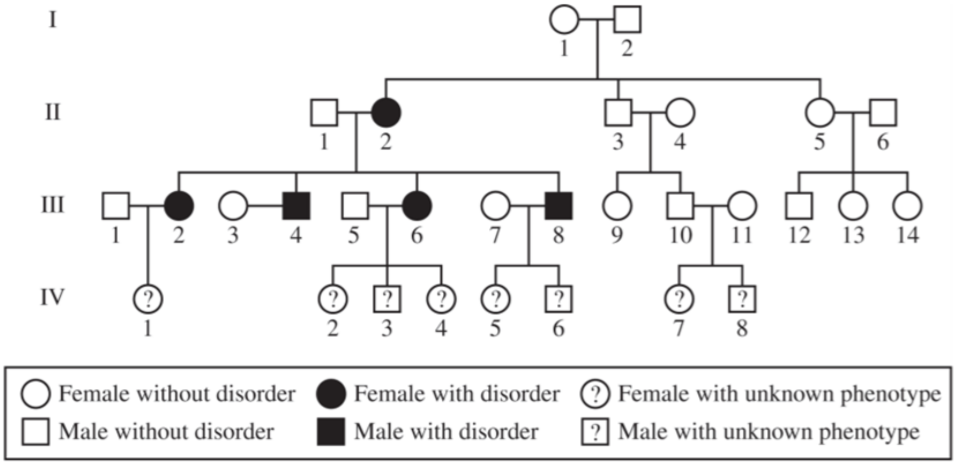

I
1
2
II
1
2
3
4
5
6
III
1
2
3
4
5
6
7
8
9
10
11
12
13
14
IV
1
2
3
4
5
6
7
8
Female without disorder
Female with disorder
Female with unknown phenotype
Male without disorder
Male with disorder
Male with unknown phenotype

Figure 1. Pedigree of a family showing individuals with the glucose metabolism disorder. A question mark indicates that the phenotype is unknown.

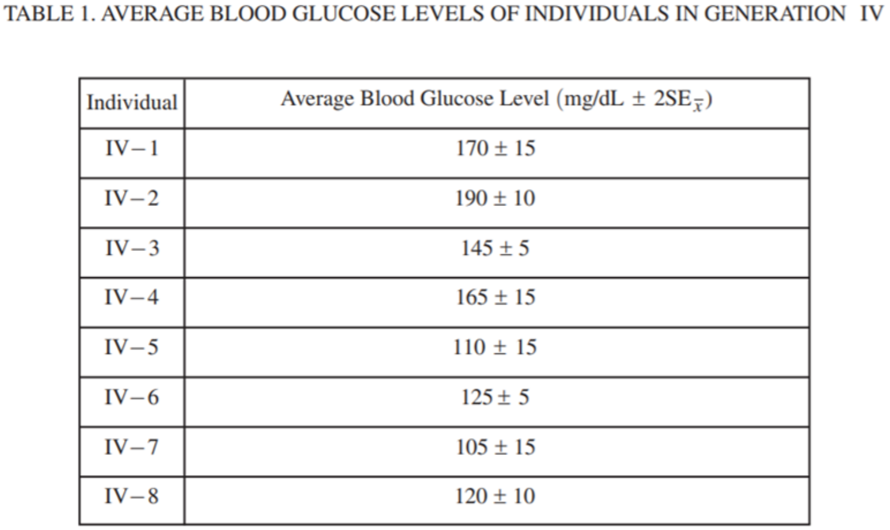


TABLE 1. AVERAGE BLOOD GLUCOSE LEVELS OF INDIVIDUALS IN GENERATION IV

Individual	Average Blood Glucose Level (mg/dL ± $2SE_{\bar{x}}$)
IV−1	170 ± 15
IV−2	190 ± 10
IV−3	145 ± 5
IV−4	165 ± 15
IV−5	110 ± 15
IV−6	125 ± 5
IV−7	105 ± 15
IV−8	120 ± 10

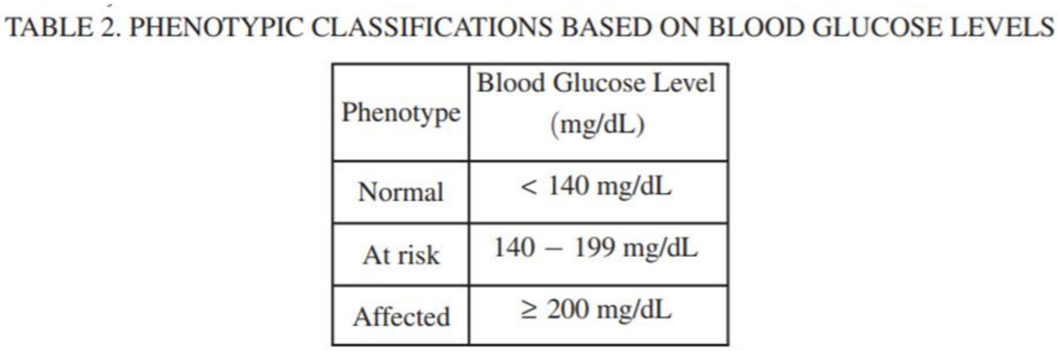
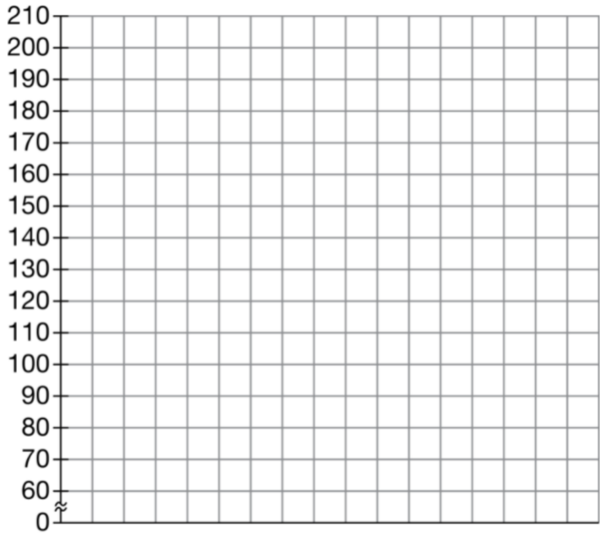


TABLE 2. PHENOTYPIC CLASSIFICATIONS BASED ON BLOOD GLUCOSE LEVELS

Phenotype	Blood Glucose Level (mg/dL)
Normal	< 140 mg/dL
At risk	140 − 199 mg/dL
Affected	≥ 200 mg/dL

(a) The disorder alters glucose metabolism. **Describe** the atoms AND types of bonds in a glucose molecule.

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph based on the data in Table 1. **Determine** one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV-1.



(c) Based on the pedigree, **identify** all individuals in generation IV who can pass on the mutation to their children.

(d) Based on the fact that individual II-2 is affected, a student claims that the disorder is inherited in an X-linked recessive pattern. Based on the student's claim, **predict** which individuals of generation III will be affected by the disorder. Based on the pedigree, **justify** why the data do NOT support the student's claim.

2021 #6

The small invertebrate krill species *Thysanoessa inermis* is adapted to cold (4°C) seawater. Over the past ten years, there has been a gradual increase in the water temperature of the krill's habitat. A sustained increase in water temperature may ultimately affect the ability of the krill to survive.

One effect of higher temperatures is protein misfolding within cells. Krill have several *hsp* genes that code for heat-shock proteins (HSPs). These proteins help prevent protein misfolding or help to refold proteins to their normal shapes.

Scientists conducted experiments on *T. inermis* to detect changes in the expression of *hsp* genes when the krill were exposed to temperatures above 4°C. An experimental group of krill was maintained in tanks with 4°C seawater and then placed into tanks with 10°C seawater for approximately three hours. The krill were then given a six-hour recovery period in the 4°C seawater tanks. A control group of krill was moved from a tank of 4°C seawater to another tank of 4°C seawater for approximately three hours and then returned to the original tank. The scientists analyzed *hsp* gene expression by measuring the concentrations of three mRNAs (I, II, III) transcribed from certain *hsp* genes in both the heat-shocked krill (Figure 1) and the control krill. For the control krill, no transcription of the *hsp* genes were detected throughout the test period (data not shown).

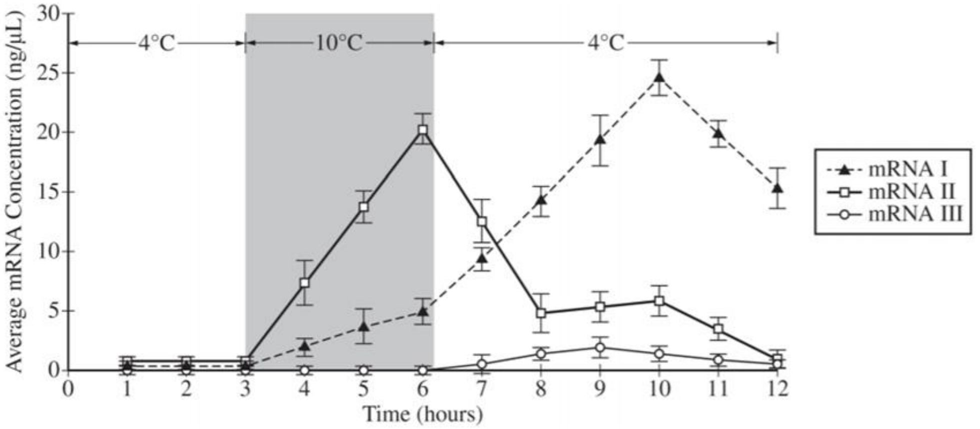


Figure 1. Average concentration of three mRNAs (I, II, III) transcribed from *hsp* genes in krill heat shocked at 10°C. Error bars represent $\pm 2SE_{\bar{x}}$.

(a) **Identify** the *hsp* mRNA that has the slowest rate of concentration increase in response to heat-shock treatment.

(b) **Describe** the trend in the average concentration of mRNA I throughout the experiment.

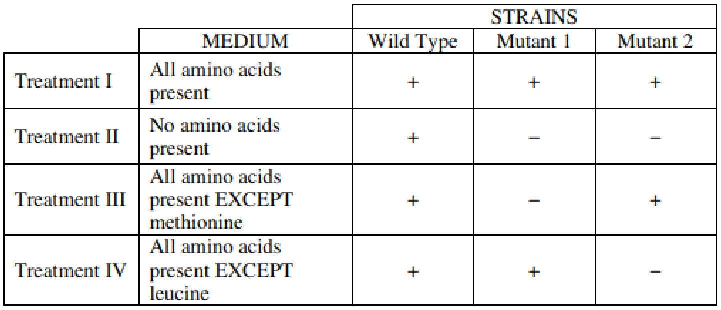
(c) The scientists hypothesized that the heat-shock protein (HSP) translated from mRNA I plays a greater role in refolding proteins than does the HSP translated from mRNA II. Use the data to **support** the hypothesis.

(d) mRNAs I and II are transcribed from the same gene. **Explain** how a cell can produce two different mRNAs from the same gene.

2019 #1

This question is in Unit 8.

2019 #6



		STRAINS		
	MEDIUM	Wild Type	Mutant 1	Mutant 2
Treatment I	All amino acids present	+	+	+
Treatment II	No amino acids present	+	–	–
Treatment III	All amino acids present EXCEPT methionine	+	–	+
Treatment IV	All amino acids present EXCEPT leucine	+	+	–

Table 1. The data show the growth of haploid *Saccharomyces cerevisiae* yeast strains on media that differ in amino acid content. A plus sign (+) indicates that the yeast strains grow, and a minus sign (–) indicates that the strains do not grow.

The yeast *Saccharomyces cerevisiae* is a single-celled organism. Amino acid synthesis in yeast cells occurs through metabolic pathways, and enzymes in the synthesis pathways are encoded by different genes. The synthesis of a particular amino acid can be prevented by mutation of a gene encoding an enzyme in the required pathway.

A researcher conducted an experiment to determine the ability of yeast to grow on media that differ in amino acid content. Yeast can grow as both haploid and diploid cells. The researcher tested two different haploid yeast strains (Mutant 1 and Mutant 2), each of which has a single recessive mutation, and a haploid wild-type strain. The resulting data are shown in Table 1.

(a) **Identify** the role of treatment I in the experiment.

(b) **Provide reasoning** to explain how Mutant 1 can grow on treatment I medium but cannot grow on treatment III medium.

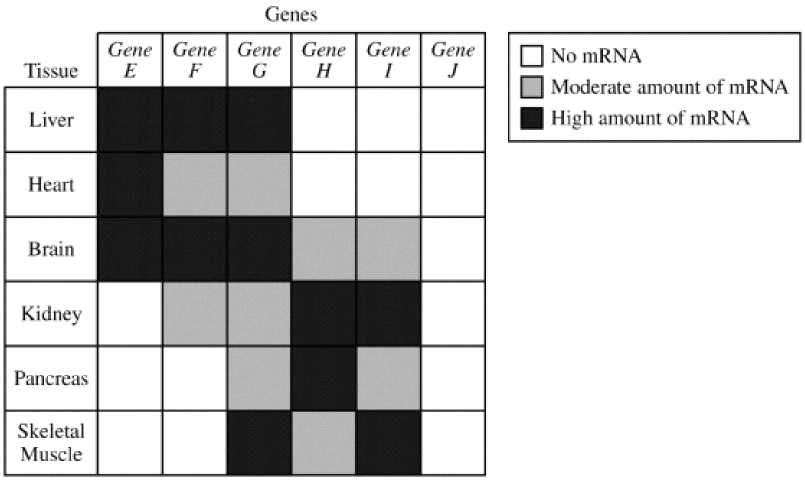
(c) Yeast mate by fusing two haploid cells to make a diploid cell. In a second experiment, the researcher mates the Mutant 1 and Mutant 2 haploid strains to produce diploid cells. Using the table provided, **predict** whether the diploid cells will grow on each of the four media. Use a plus sign (+) to indicate growth and a minus sign (-) to indicate no growth.

		STRAINS			
	MEDIUM	Wild Type (haploid)	Mutant 1 (haploid)	Mutant 2 (haploid)	Diploid Cells Produced by Mating Mutant 1 and Mutant 2
Treatment I	All amino acids present	+	+	+	
Treatment II	No amino acids present	+	–	–	
Treatment III	All amino acids present EXCEPT methionine	+	–	+	
Treatment IV	All amino acids present EXCEPT leucine	+	+	–	

2019 #7

A researcher is studying patterns of gene expression in mice. The researcher collected samples from six different tissues in a healthy mouse and measured the amount of mRNA from six genes. The data are shown in Figure 1.

mRNA EXPRESSION LEVELS



Tissue	Gene *E*	Gene *F*	Gene *G*	Gene *H*	Gene *I*	Gene *J*
Liver	■	■	■	□	□	□
Heart	■	▨	▨	□	□	□
Brain	■	■	■	▨	▨	□
Kidney	□	▨	▨	■	■	□
Pancreas	□	□	▨	■	▨	□
Skeletal Muscle	□	□	■	▨	■	□

□ No mRNA
▨ Moderate amount of mRNA
■ High amount of mRNA

Figure 1. mRNA expression levels of six genes

(a) Based on the data provided, **identify** the gene that is most likely to encode a protein that is an essential component of glycolysis. **Provide reasoning** to support your identification.

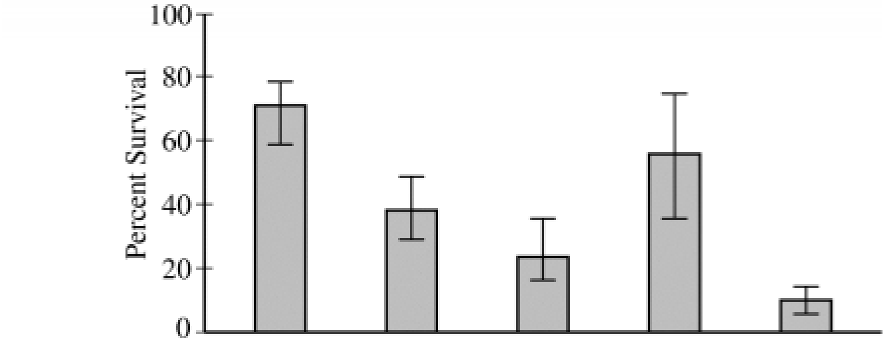
(b) The researcher observed that tissues with a high level of *gene H* mRNA did not always have gene H protein. **Provide reasoning** to explain how tissues with high *gene H* mRNA levels can have no gene H protein.

2018 #1

This question is in Unit 7.

2018 #4

The common bedbug (*Cimex lectularius*) is a species of insect that is becoming increasingly resistant to insecticides. Bedbugs possess several genes suspected of contributing to the resistance, including *P450, Abc8,* and *Cps*. To investigate the role of these genes in insecticide resistance, researchers deleted one or more of these genes in different strains of bedbugs, as indicated in Figure 1, and treated the strains with the insecticide beta-cyfluthrin. Each strain was genetically identical except for the deleted gene(s) and was equally fit in the absence of beta-cyfluthrin. The percent survival of each strain following beta-cyfluthrin treatment is shown in Figure 1.



Strain	I	II	III	IV	V
P450	+	–	+	+	–
Abc8	+	+	–	+	–
Cps	+	+	+	–	+

+ = Wildtype
– = Deletion

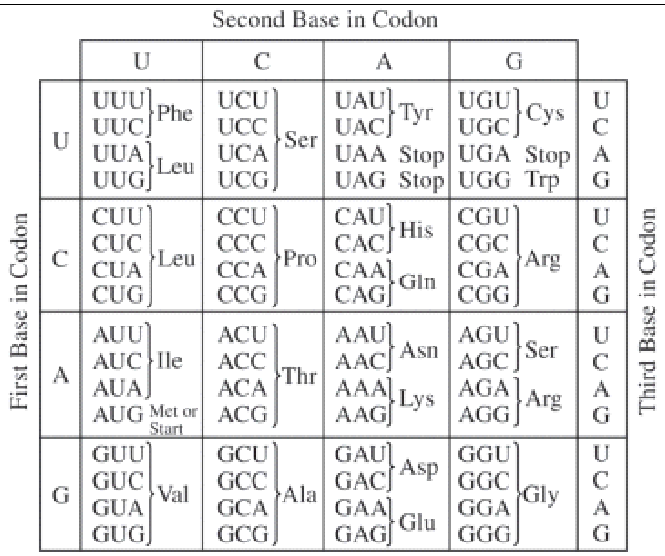
Figure 1. Percent survival of five strains of bedbugs treated with beta-cyfluthrin. A (+) indicates the gene is present; a (–) indicates the gene is deleted. Error bars represent the 95% confidence interval.

(a) **Identify** the control strain in the experiment. Use the means and confidence intervals in Figure 1 to **justify** the claim that *Abc8* is effective at providing resistance to beta-cyfluthrin.

(b) *P450* encodes an enzyme that detoxifies insecticide. *Abc8* encodes a transporter protein that pumps insecticides out of cells. *Cps* encodes external structural protein located in the exoskeleton that reduces the absorption of insecticides. Based on this information and the data in Figure 1, **explain** how a deletion of both *P450* and *Abc8* results in lower survival in bedbugs compared with a deletion of *Cps* only.

2017 #3

Gibberellin is the primary plant hormone that promotes stem elongation. GA 3-beta-hydrozylase (*GA3H*) is the enzyme that catalyzes the reaction that converts a precursor of gibberellin to the active form of gibberellin. A mutation in the *GA3H* gene results in a short plant phenotype. When a pure-breeding tall plant is crossed with a pure-breeding short plant, all offspring in the F_1 generation are tall. When the F_1 plants are crossed with each other, 75 percent of the plants in the F_2 generation are tall and 25 percent of the plants are short.



First Base in Codon	Second Base in Codon: U	C	A	G	Third Base in Codon
U	UUU UUC } Phe UUA UUG } Leu	UCU UCC UCA UCG } Ser	UAU UAC } Tyr UAA Stop UAG Stop	UGU UGC } Cys UGA Stop UGG Trp	U C A G
C	CUU CUC CUA CUG } Leu	CCU CCC CCA CCG } Pro	CAU CAC } His CAA CAG } Gln	CGU CGC CGA CGG } Arg	U C A G
A	AUU AUC AUA } Ile AUG Met or Start	ACU ACC ACA ACG } Thr	AAU AAC } Asn AAA AAG } Lys	AGU AGC } Ser AGA AGG } Arg	U C A G
G	GUU GUC GUA GUG } Val	GCU GCC GCA GCG } Ala	GAU GAC } Asp GAA GAG } Glu	GGU GGC GGA GGG } Gly	U C A G

Figure 1. The universal genetic code

(a) The wild-type allele encodes a GA3H enzyme with alanine (Ala), a nonpolar amino acid, at position 229. The mutant allele encodes a GA3H enzyme with threonine (Thr), a polar amino acid, at position 229. **Describe** the effect of the mutation on the enzyme and **provide reasoning** to support how this mutation results in a short plant phenotype in homozygous recessive plants.

(b) Using the codon chart provided, **predict** the change in the codon sequence that resulted in the substitution of alanine for threonine at amino acid position 229.

(c) **Describe** how individuals with one (heterozygous) or two (homozygous) copies of the wild-type *GA3H* allele can have the same phenotype.

2017 #6

A comet assay is a technique used to determine the amount of double-stranded breaks in DNA (DNA damage) in cells. The nucleus of an individual cell is placed on a microscope slide coated with an agarose gel. An electric current is applied to the gel that causes DNA to move (electrophoresis), and the DNA is stained with a fluorescent dye. When viewed using a microscope, undamaged DNA from the nucleus appears as a round shape (the head), and the fragments of damaged DNA extend out from the head (the tail). The length of the tail corresponds to the amount of the damage in the DNA (see Figure 1).

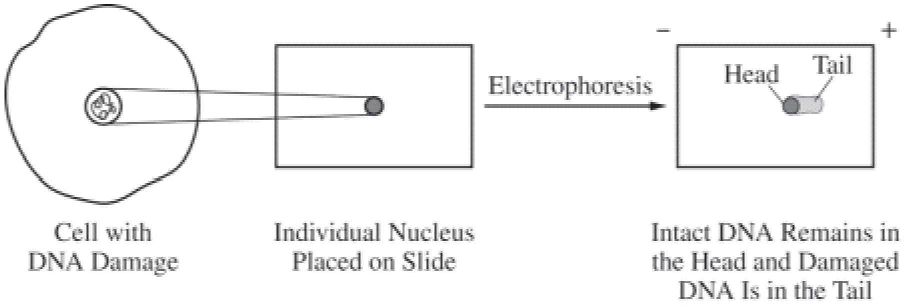

Electrophoresis
−
+
Head
Tail
Cell with DNA Damage
Individual Nucleus Placed on Slide
Intact DNA Remains in the Head and Damaged DNA Is in the Tail

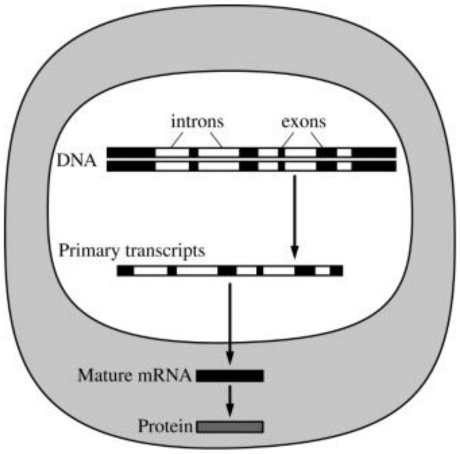
Figure 1. Comet assay to detect double-stranded breaks in DNA

(a) To explain the movement of DNA fragments in the comet assay, **identify** one property of DNA and **provide reasoning** to support how the property contributes to the movement during the comet assay technique.

(b) In a different experiment, cells are treated with a chemical mutagen that causes only nucleotide substitutions in DNA. **Predict** the likely results of a comet assay from this treatment.

2016 #4

The figure represents the process of expression of gene X in a eukaryotic cell.


introns
exons
DNA
Primary transcripts
Mature mRNA
Protein

(a) The primary transcript in the figure is 15 kilobases (kb) long, but the mature mRNA is 7kb in length. **Describe** the modification that most likely resulted in the 8 kb difference in length of the mature mRNA molecule. **Identify** in your response the location in the cell where the change occurs.

(b) **Predict** the length of the mature gene X mRNA if the full-length gene is introduced and expressed in prokaryotic cells. **Justify** your prediction.

2016 #6

Living and dead organisms continuously shed DNA fragments, known as eDNA, into the environment. To detect eDNA fragments in the environment, the polymerase chain reaction (PCR) can be used to amplify specific eDNA fragments. eDNA fragments of different lengths persist in the environment for varying amounts of time before becoming undetectable (Figure 1).

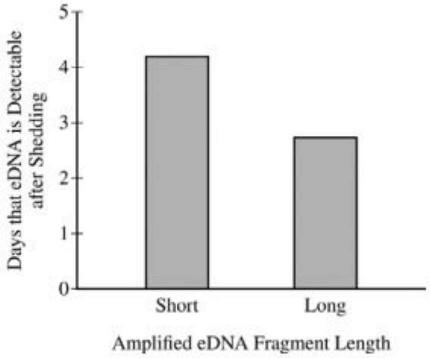


Figure 1. Detectability of eDNA fragments of varying lengths

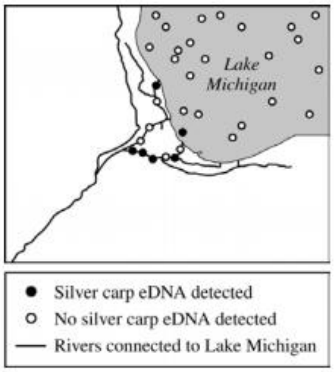

Lake Michigan
● Silver carp eDNA detected
○ No silver carp eDNA detected
— Rivers connected to Lake Michigan

Figure 2. Map of the waterways that connect a nearby river system to Lake Michigan

To investigate whether silver carp, an invasive fish, have moved from a nearby river system into Lake Michigan, researchers tested water samples for the presence of eDNA specific to silver carp (Figure 2).

(a) **Justify** the use of eDNA sampling as an appropriate technique for detecting the presence of silver carp in an environment whether many different species of fish are found. **Propose** ONE advantage of identifying long eDNA fragments as opposed to short fragments for detecting silver carp.

(b) The researchers tested a large number of water samples from Lake Michigan and found eDNA specific to silver carp in a single sample in the lake, as indicated in Figure 2. The researchers concluded that the simple positive sample was a false positive and that no silver carp had entered Lake Michigan. **Provide reasoning** other than human error to support the researcher's claim.

2015 #7

Smell perception in mammals involves the interactions of airborne odorant molecules from the environment with receptor proteins on the olfactory neurons in the nasal cavity. The binding of odorant molecules to the receptor proteins triggers action potentials in the olfactory neurons and results in transmission of information to the brain. Mammalian genomes typically have approximately 1,000 functional odorant-receptor genes, each encoding a unique odorant receptor.

(a) **Describe** how the signal is transmitted across the synapse from an activated olfactory sensory neuron to the interneuron that transmits the information to the brain.

(b) **Explain** how the expression of a limited number of odorant receptor genes can lead to the perception of thousands of odors. Use the evidence about the number of odorant receptor genes to **support** your answer.

2014 #5

This question is in Unit 8.

2014 #8

This question is in Unit 7.

2013 #5

The table below shows the amino acid sequence of the carboxyl-terminal segment of a conserved polypeptide from four different, but related, species. Each amino acid is represented by a three-letter abbreviation, and the amino acid residues in the polypeptide chains are numbered from the amino end to the carboxyl end. Empty cells indicate no amino acid is present.

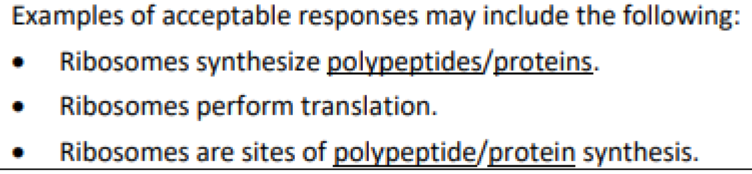
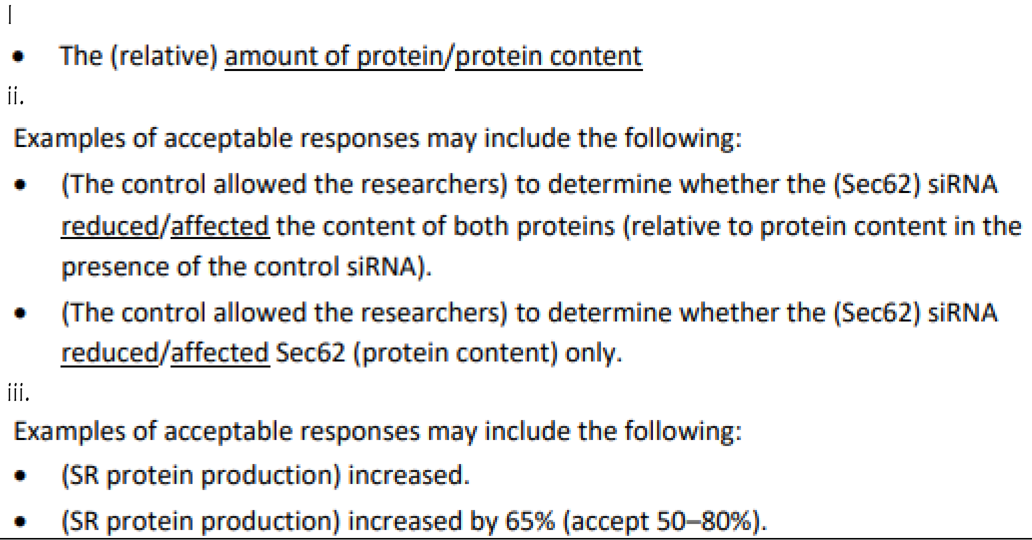
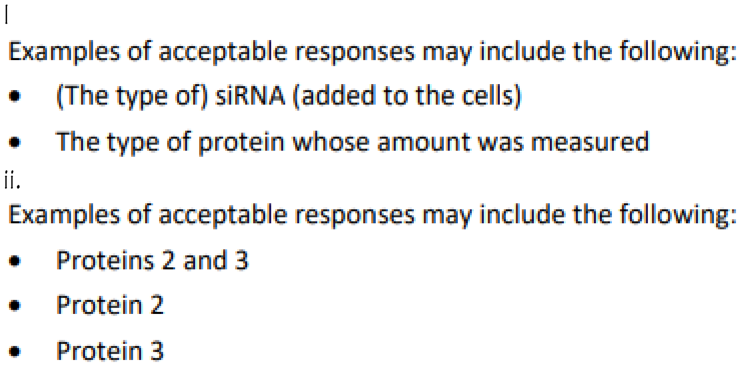
	Relative Amino Acid Position									
Species	1	2	3	4	5	6	7	8	9	10
I	Val	His	Leu	Val	Glu	Glu	His	Val	Glu	His
II	Val	His	Leu	Lys	Glu	Glu	His	Val	Glu	His
III	Val	His	Leu	Val	Glu	Glu	His	Val		
IV	Val	His	Leu	Val	Arg	Trp	Ala	Cys	Met	Asp

(a) Assuming that species I is the ancestral species of the group, **explain** the most likely genetic change that produced the polypeptide in species II and the most likely genetic change that produced the polypeptide in species III.

(b) **Predict** the effects of the mutation on the structure and function of the resulting protein in species IV. **Justify** your prediction.

Free Response Scoring Guidelines

2025 #1	
Course Content	**Practice and Skill**
2.1: Cell Structure and Function • 2.1.A*: Explain how the structure and function of subcellular components and organelles contribute to the function of cells. 2.6: Facilitated Diffusion • 2.6.A*: Explain how the structure of a molecule affects its ability to pass through the plasma membrane. 6.4: Translation • 6.4.A*: Explain how the phenotype of an organism is determined by its genotype.	1.A: Describe biological concepts and processes. 3.C: Identify experimental procedures that align with the question 4.B: Describe data from a table or graph 5.A: Perform mathematical calculations 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines
(a)	 Examples of acceptable responses may include the following: • Ribosomes synthesize polypeptides/proteins. • Ribosomes perform translation. • Ribosomes are sites of polypeptide/protein synthesis.
(b)	 I • The (relative) amount of protein/protein content ii. Examples of acceptable responses may include the following: • (The control allowed the researchers) to determine whether the (Sec62) siRNA reduced/affected the content of both proteins (relative to protein content in the presence of the control siRNA). • (The control allowed the researchers) to determine whether the (Sec62) siRNA reduced/affected Sec62 (protein content) only. iii. Examples of acceptable responses may include the following: • (SR protein production) increased. • (SR protein production) increased by 65% (accept 50–80%).
(c)	 I Examples of acceptable responses may include the following: • (The type of) siRNA (added to the cells) • The type of protein whose amount was measured ii. Examples of acceptable responses may include the following: • Proteins 2 and 3 • Protein 2 • Protein 3

	iii. • 87 (amino acids) [(495/3)—(234/3)]
(d)	I. • Only protein 1 showed a reduced amount/percentage of transport when cells were treated with Sec62 siRNA. ii. • Amino acids (at the amino terminus) that have similar polarity to/opposite charge to (the R groups of amino acids lining) the protein channel are more likely to pass through the channel (than are proteins where the amino terminus contains amino acids with dissimilar polarity or similar charge).

Scoring Statistics

	Max Points:	**Mean Score:**
Point A1	1.0	0.64
Point B1	1.0	0.79
Point B2	1.0	0.16
Point B3	1.0	0.83
Point C1	1.0	0.76
Point C2	1.0	0.89
Point C3	1.0	0.49
Point D1	1.0	0.14
Point D2	1.0	0.02

Overall Mean Score: 4.74

2025 #6

Course Content	Practice and Skill
6.7: Mutations • 6.7.B Explain how changes in genotype may result in changes in phenotype.	4.B: Describe data from a table or graph 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.

Part	Scoring Guidelines
(a)	• *ald1/del*
(b)	Examples of acceptable responses may include the following: • More ALD protein is produced by *ald3/ald23* cells (than by *ald23/del* cells). • Less ALD protein is produced by *ald23/del* cells (than by *ald3/ald23* cells). • No ALD protein is produced by *ald23/del* cells (whereas it is produced by *ald3/ald23* cells).

(c)	Examples of acceptable responses may include the following: • (With half as much protein) the *WT/del* cells show no difference in percent of (gamete forming metaphase cells with) ALD-associated filaments. • The data for the *WT/del* relative to/in comparison with the *WT/WT* cells support the scientists' hypothesis.
(d)	Examples of acceptable responses may include the following: • (The phenotypes) differ because only the *WT/del* flies produce enough functional (ALD) protein to generate a wild-type phenotype. • When one allele encodes functional ALD protein (in *WT/del* flies), the flies can generate a wild-type phenotype/produce ALD-associated filaments in a similar amount as *WT/WT* flies. • Both genotypes produced ALD protein, but the *ald1* mutation resulted in a protein with reduced function (compared with *WT*, resulting in a different phenotype).

Scoring Statistics

	Max Points:	**Mean Score:**
Part A	1.0	0.73
Part B	1.0	0.67
Part C	1.0	0.25
Part D	1.0	0.04

Overall Mean Score: 1.7

2024 #6

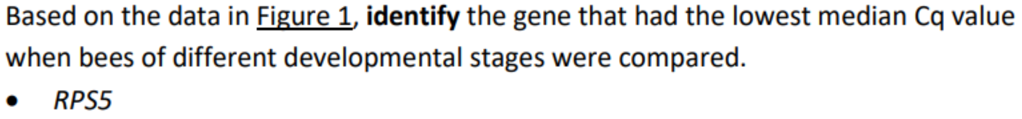
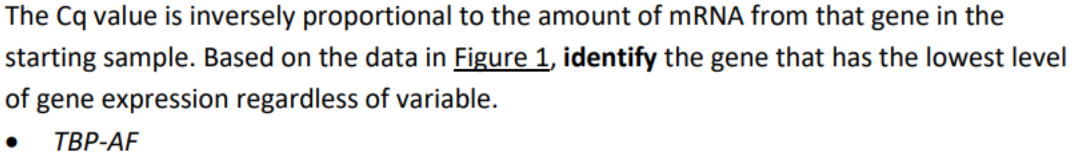
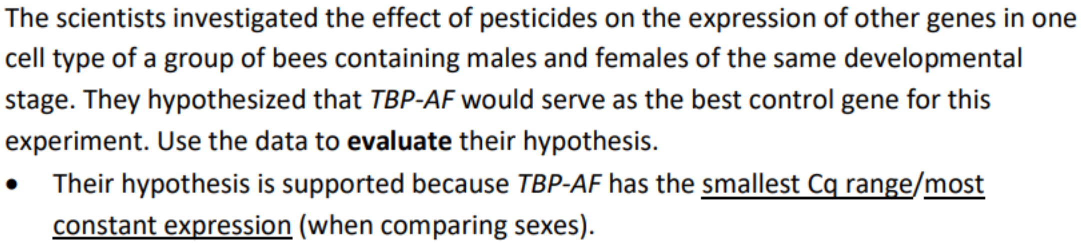
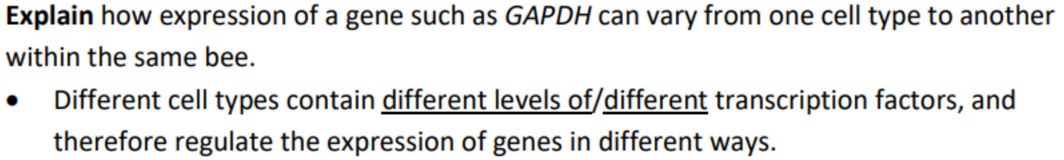
Course Content	Practice and Skill
6.4: Translation • 6.4.A: Explain how the phenotype of an organism is determined by its genotype.	4.B: Describe data from a table or graph 5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.

Part	Scoring Guidelines
(a)	• 150
(b)	Accept one of the following: • There is greater variation in (the translation rate of) UGG codons (than in the translation rate of AUU codons). • (The translation rate of) UGG ranges from 50 (ms/codon) to 950 (ms/codon), while (the translation rate of) AUU ranges from 50 (ms/codon) to 450 (ms/codon).
(c)	Accept one of the following: • The (average) translation rate of UGG is slower (than that of AUU). • Translation of UGG takes longer (per codon than does translation of AUU). • More of the UGG codons were translated at slower rates (than AUU codons were).
(d)	• Certain codons are translated at faster rates than are others (and result in increased levels of protein production from a particular mRNA).

Scoring Statistics:	
Mean: 1.67	Standard Deviation: 1.13

2023 #6

Course Content	Practice and Skill
6.3: Transcription and RNA Processing - 6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein. 6.5: Regulation of Gene Expression - 6.5.A: Describe the types of interactions that regulate gene expression. 6.6: Gene Expression and Cell Specialization - 6.6.B: Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.	4.B: Describe data from a table or graph 5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.

Part	Scoring Guidelines
(a)	 Based on the data in Figure 1, **identify** the gene that had the lowest median Cq value when bees of different developmental stages were compared. - *RPS5*
(b)	 The Cq value is inversely proportional to the amount of mRNA from that gene in the starting sample. Based on the data in Figure 1, **identify** the gene that has the lowest level of gene expression regardless of variable. - *TBP-AF*
(c)	 The scientists investigated the effect of pesticides on the expression of other genes in one cell type of a group of bees containing males and females of the same developmental stage. They hypothesized that *TBP-AF* would serve as the best control gene for this experiment. Use the data to **evaluate** their hypothesis. - Their hypothesis is supported because *TBP-AF* has the smallest Cq range/most constant expression (when comparing sexes).
(d)	 **Explain** how expression of a gene such as *GAPDH* can vary from one cell type to another within the same bee. - Different cell types contain different levels of/different transcription factors, and therefore regulate the expression of genes in different ways.

Scoring Statistics:	
Mean: 1.48	Standard Deviation: 0.95

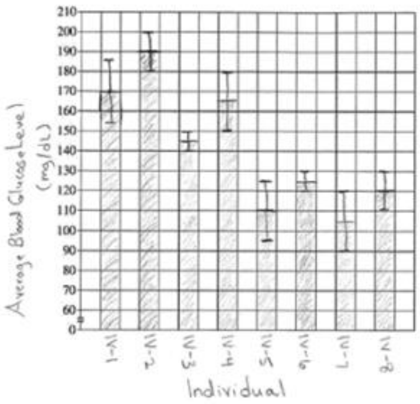
2022 #6

Course Content	Practice and Skill
6.3: Transcription and RNA Processing • 6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein. 6.4: Translation • 6.4.A: Explain how the phenotype of an organism is determined by its genotype. 6.6: Gene Expression and Cell Specialization • 6.6.A: Explain how the binding of transcription factors to promoter regions affects gene expression and the phenotype of the organism.	4.B: Describe data from a table or graph 5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.

Part	Scoring Guidelines
(a)	Based on the data, **identify** which cap structure is most likely to protect the end of the mRNAs from degradation. • Modified cap II
(b)	Based on the data for the mRNAs with modified caps, **describe** the relationship between the mRNA half-life and the total amount of protein produced. Accept one of the following: • A longer mRNA half-life is associated with more protein. • There is a positive correlation/relationship.
(c)	After examining the data on mRNA half-lives and the amount of protein produced, the researchers hypothesized that each mRNA molecule with modified cap I was translated more frequently than was each mRNA molecule with the normal GTP cap. **Evaluate** their hypothesis by comparing the data in Table 1. • The data support their hypothesis because the half-lives of the two mRNAs are the same, but the amount of protein produced from the mRNA with modified cap I is more than (four times as much as) that produced from the mRNA with the normal cap.
(d)	Introduction of mRNAs into cells allows the cells to produce foreign proteins that they might not normally produce. **Explain** why the production of a foreign protein may be more likely from the introduction of mRNA than DNA into cells. Accept one of the following: • Protein production from the DNA requires (transcription) factors to initiate transcription. • Protein production from the mRNA does not depend on (correct posttranscriptional) processing of the pre-mRNA. • The cells may be unable to transcribe the DNA (while mRNA can be directly translated).

Scoring Statistics:	
Mean: 1.57	Standard Deviation: 0.92

<table>
<tr><th colspan="2">2021 #2</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>1.2: Elements of Life
• 1.2.A: Describe the composition of macromolecules required by living organisms.
5.4: Non-Mendelian Genetics
• 5.4.A: Explain deviations from Mendel's model of the inheritance of traits.
6.7: Mutations
• 6.7.A: Describe the various types of mutation.</td><td>1.A: Describe biological concepts and processes.
4.A: Construct a graph to represent the data
4.B: Describe data from a table or graph
5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different.</td></tr>
</table>

<table>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>The disorder alters glucose metabolism. Describe the atoms AND types of bonds in a glucose molecule.
• The atoms are carbon, hydrogen, and oxygen (C, H, and O) and are held together by covalent bonds.</td></tr>
<tr><td>(b)</td><td>Use the template provided to construct an appropriately labeled graph based on the data in Table 1.


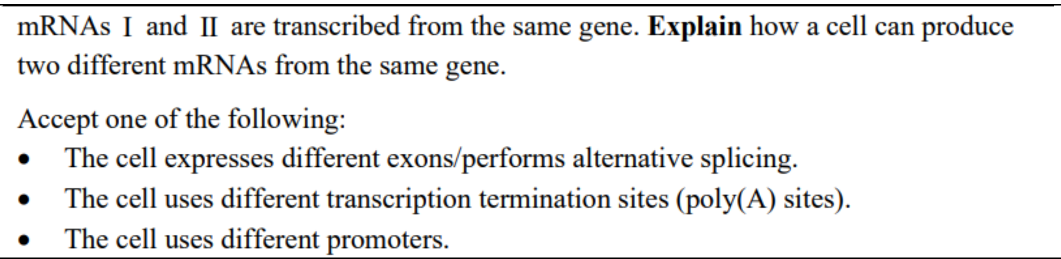
• Point distribution: Axis labels; plotting in a bar graph or modified bar graph; error bars
Determine one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV-1.
• IV-3</td></tr>
<tr><td>(c)</td><td>Based on the pedigree, identify all individuals in generation IV who can pass on the mutation to their children.
• IV-1, IV-2, IV-4</td></tr>
</table>

(d)	Based on the fact that individual II-2 is affected, a student claims that the disorder is inherited in an X-linked recessive pattern. Based on the student's claim, **predict** which individuals of generation III will be affected by the disorder. • III-4 and III-8 Based on the pedigree, **justify** why the data do NOT support the student's claim. Accept one of the following: • The data do not support the claim because females III-2 and III-6 have the disorder and, if inheritance is X-linked recessive, they could only do so if their father II-1 had the disorder, which he does not. • The data instead support mitochondrial inheritance, because all of the offspring of individual II-2 , not only the sons, have the disorder.

Scoring Statistics:	
Mean: 3.17	Standard Deviation: 1.98

2021 #6	
Course Content	**Practice and Skill**
6.3: Transcription and RNA Processing • 6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein. 6.6: Gene Expression and Cell Specialization • 6.6.B: Explain the connection between the regulation of gene expression and phenotypic differences in cells and organisms.	4.B: Describe data from a table or graph 5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.

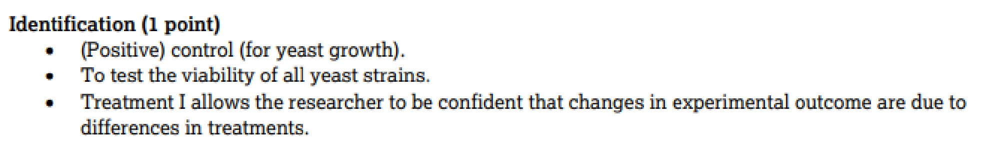
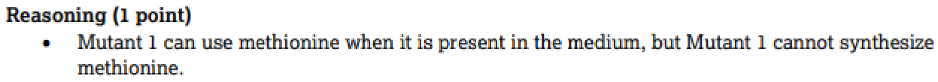
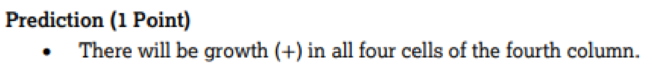
Part	Scoring Guidelines
(a)	**Identify** the *hsp* mRNA that has the slowest rate of concentration increase in response to heat-shock treatment. • (mRNA) III
(b)	**Describe** the trend in the average concentration of mRNA I throughout the experiment. • (No change in concentration from 1 to 3 hours) increased concentration (slightly) between 3 and 6 hours/during the heat shock, increased concentration at a greater rate from 6 to 10 hours/for 4 hours after the heat shock, and then decreased concentration after hour 10.
(c)	The scientists hypothesized that the heat-shock protein (HSP) translated from mRNA I plays a greater role in refolding proteins than does the HSP translated from mRNA II . Use the data to **support** the hypothesis. • mRNA I is still expressed at a high level after the heat-shock period, while mRNA II levels decrease after the heat shock, when proteins would need to be refolded.

(d)	 mRNAs I and II are transcribed from the same gene. **Explain** how a cell can produce two different mRNAs from the same gene. Accept one of the following: • The cell expresses different exons/performs alternative splicing. • The cell uses different transcription termination sites (poly(A) sites). • The cell uses different promoters.

Scoring Statistics:	
Mean: 1.26	Standard Deviation: 0.85

2019 #6

Course Content	Practice and Skill
5.2: Meiosis and Genetic Diversity • 5.2.A: Explain how the process of meiosis generates genetic diversity. 6.7: Mutations • 6.7.B: Explain how changes in genotype may result in changes in phenotype.	3.C: Identify experimental procedures that align with the question 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	 **Identification (1 point)** • (Positive) control (for yeast growth). • To test the viability of all yeast strains. • Treatment I allows the researcher to be confident that changes in experimental outcome are due to differences in treatments.
(b)	 **Reasoning (1 point)** • Mutant 1 can use methionine when it is present in the medium, but Mutant 1 cannot synthesize methionine.
(c)	 **Prediction (1 Point)** • There will be growth (+) in all four cells of the fourth column.

Scoring Statistics:	
Mean: 0.88	Standard Deviation: 0.57

2019 #7

Course Content	Practice and Skill
3.5: Cellular Respiration • 3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions. 6.4: Translation • 6.4.A: Explain how the phenotype of an organism is determined by its genotype.	2.A: Describe characteristics of visual representations of biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines

(a)	**Identification (1 point)** - *Gene G* **Reasoning (1 point)** - (*Gene G*) is the only gene expressed in all (six) tissues, AND glycolysis occurs in all (six) tissues. - (*Gene G*) mRNA is the only mRNA present in all (six) tissues, AND glycolysis occurs in all (six) tissues.
(b)	**Reasoning (1 point)** - The mRNA is not exported from the nucleus. - *Gene H* mRNA is not translated/RNA interference prevent(s) translation. - Post-transcriptional modifications.
Scoring Statistics:	
Mean: 0.69	Standard Deviation: 0.80

<table>
<tr><th colspan="3">2018 #4</th></tr>
<tr><th colspan="2">Course Content</th><th>Practice and Skill</th></tr>
<tr><td colspan="2">6.7: Mutations
6.7.B: Explain how changes in genotype may result in changes in phenotype.
6.7.C: Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.</td><td>3.C: Identify experimental procedures that align with the question
5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different.
6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.</td></tr>
<tr><th>Part</th><th colspan="2">Scoring Guidelines</th></tr>
<tr><td>(a)</td><td colspan="2">Identification (1 point)
Strain I
Justification (1 point)
Error bars/CIs from strain I/control/WT do not overlap with strain III/<i>Abc8</i> deleted strain.
Mean % survival of strain III/<i>Abc8</i> deletion falls outside the 95% confidence interval of strain I/control/WT.
Strain III/<i>Abc8</i> deletion shows a statistically significant difference from strain I/control.</td></tr>
<tr><td>(b)</td><td colspan="2">Explanation (1 point per row; 2 points maximum)
<table>
<tr><th>Strain</th><th><i>P450</i> and <i>Abc8</i></th><th><i>Cps</i> only</th><th>Explanation</th></tr>
<tr><td>V</td><td>Deleted</td><td>Present</td><td>Bedbugs can neither detoxify nor pump out insecticide, which results in a lower chance of bedbug survival.</td></tr>
<tr><td>IV</td><td>Present</td><td>Deleted</td><td>Bedbugs can detoxify and pump out insecticide, which results in a higher chance of bedbug survival.</td></tr>
</table></td></tr>
<tr><th colspan="3">Scoring Statistics:</th></tr>
<tr><td colspan="2">Mean: 1.41</td><td>Standard Deviation: 1.03</td></tr>
</table>

2017 #3	
Course Content	Practice and Skill
6.7: Mutations	1.A: Describe biological concepts and processes.

- 6.7.A: Describe the various types of mutation. - 6.7.B: Explain how changes in genotype may result in changes in phenotype. 5.3: Mendelian Genetics - 5.3.A: Explain the inheritance of genes and traits as described by Mendel's laws.	6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	see below

(a)

Description (1 point)	**Reasoning (1 point)**
The amino acid substitution changes the shape/structure/function of the protein.	The mutation decreases/eliminates gibberellin production.

(b) **Prediction (1 point maximum)**

- G ↔ A in the first position (of the codon)
- 5′-GCN-3′ ↔ 5′-ACN-3′
- 5′-NGC-3′ ↔ 5′-NGT-3′ in the template strand of DNA

(c) **Description (1 point)**

- Enough active enzyme is produced from one wild-type/dominant allele.
- Enough gibberellin is produced in the presence of one wild-type/dominant allele.

Scoring Statistics:	
Mean: 1.10	Standard Deviation: 1.15

2017 #6

Course Content	Practice and Skill
6.8: Biotechnology 6.8.A: Explain the use of genetic engineering techniques in analyzing or manipulating DNA.	1.A: Describe biological concepts and processes. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part | Scoring Guidelines

(a)

Identification (1 point)	**Reasoning (1 point)**
DNA has a (negative) charge.	DNA moves toward the positive/oppositely charged pole.
DNA can be different sizes.	(Different size DNA fragments) move at different rates.

(b) **Prediction (1 point)**

- Head (only) OR (head with) no tail.
- Tail will be shorter than a cell with double-stranded breaks in DNA.

Scoring Statistics:	
Mean: 0.75	Standard Deviation: 1.02

2016 #4

Course Content	Practice and Skill
6.3: Transcription and RNA Processing - 6.3.A: Describe the mechanisms by which genetic information flows from DNA to RNA to protein.	1.A: Describe biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part | Scoring Guidelines

<table>
<tr><td>(a)</td><td colspan="2">Describe process (1 point)
• Removal of introns
• RNA processing

Identification (1 point)
• Nucleus</td></tr>
<tr><td>(b)</td><td colspan="2">Prediction (1 point)
• 15 kb
• Longer than the mature mRNA in the eukaryote

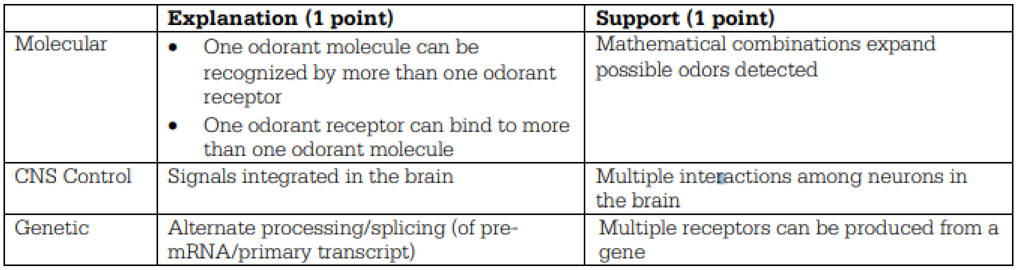
Justification (1 point)
• mRNA processing typically does not occur in prokaryotes</td></tr>
<tr><td colspan="3">Scoring Statistics:</td></tr>
<tr><td colspan="2">Mean: 1.43</td><td>Standard Deviation: 1.37</td></tr>
</table>

<table>
<tr><th colspan="3">2016 #6</th></tr>
<tr><th colspan="2">Course Content</th><th>Practice and Skill</th></tr>
<tr><td colspan="2">6.8: Biotechnology
• 6.8.A: Explain the use of genetic engineering techniques in analyzing or manipulating DNA.</td><td>1.C: Explain biological concepts and processes in applied contexts.
6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.
6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories.</td></tr>
<tr><th>Part</th><th colspan="2">Scoring Guidelines</th></tr>
<tr><td>(a)</td><td colspan="2">Justify (1 point)
• eDNA allows detection of the fish without visual identification/catching the fish.

Proposed advantage (1 point)
• Longer fragments indicate <u>more</u> recent presence of fish.
• Longer fragments are more likely to contain a sequence that is specific to silver carp.
• Longer sequences/more base pairs may increase accuracy/specificity/confidence that the eDNA is from a silver carp and not a related species.</td></tr>
<tr><td>(b)</td><td colspan="2">Reasoning (1 point)
• eDNA entered the lake by means other than the fish (e.g., river flow, boats, waste from predators).</td></tr>
<tr><td colspan="3">Scoring Statistics:</td></tr>
<tr><td colspan="2">Mean: 0.79</td><td>Standard Deviation: 0.81</td></tr>
</table>

<table>
<tr><th colspan="2">2015 #7</th></tr>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>Description (1 point)
• Neurotransmitters are released from the olfactory neuron and bind to receptors in the postsynaptic neuron.</td></tr>
</table>

(b)



	Explanation (1 point)	**Support (1 point)**
Molecular	- One odorant molecule can be recognized by more than one odorant receptor - One odorant receptor can bind to more than one odorant molecule	Mathematical combinations expand possible odors detected
CNS Control	Signals integrated in the brain	Multiple interactions among neurons in the brain
Genetic	Alternate processing/splicing (of pre-mRNA/primary transcript)	Multiple receptors can be produced from a gene

Note: The nervous system is no longer in scope

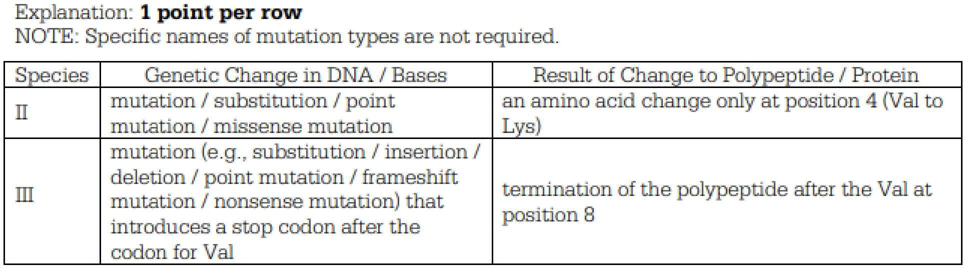
Scoring Statistics:	
Mean: 0.43	Standard Deviation: 0.72

2013 #5

Course Content	Practice and Skill
6.7: Mutations - 6.7.A: Describe the various types of mutation. - 6.7.C: Explain how alterations in DNA sequences contribute to variation that can be subject to natural selection.	

Part — **Scoring Guidelines**

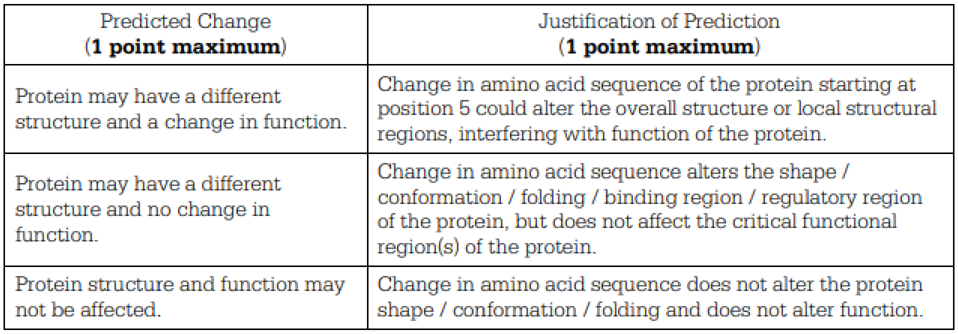
(a)



Explanation: **1 point per row**
NOTE: Specific names of mutation types are not required.

Species	Genetic Change in DNA / Bases	Result of Change to Polypeptide / Protein
II	mutation / substitution / point mutation / missense mutation	an amino acid change only at position 4 (Val to Lys)
III	mutation (e.g., substitution / insertion / deletion / point mutation / frameshift mutation / nonsense mutation) that introduces a stop codon after the codon for Val	termination of the polypeptide after the Val at position 8

(b)



Predicted Change (**1 point maximum**)	Justification of Prediction (**1 point maximum**)
Protein may have a different structure and a change in function.	Change in amino acid sequence of the protein starting at position 5 could alter the overall structure or local structural regions, interfering with function of the protein.
Protein may have a different structure and no change in function.	Change in amino acid sequence alters the shape / conformation / folding / binding region / regulatory region of the protein, but does not affect the critical functional region(s) of the protein.
Protein structure and function may not be affected.	Change in amino acid sequence does not alter the protein shape / conformation / folding and does not alter function.

Scoring Statistics:	
Mean: 1.18	Standard Deviation:1.32

Unit 7: Natural Selection

7.1 Introduction to Natural Selection	**7.1.A** Describe the causes of natural selection. **7.1.B** Explain how natural selection affects populations.
7.2 Natural Selection	**7.1.B** Explain how natural selection affects populations. **7.2.B** Explain how variation in molecules within cells connects to the fitness of an organism.
7.3 Artificial Selection	**7.3.A** Explain how humans can affect diversity within a population.
7.4 Population Genetics	**7.4.A** Explain how random occurrences affect the genetic makeup of a population. **7.4.B** Describe the role of random processes in the evolution of specific populations. **7.4.C** Describe the change in the genetic makeup of a population over time.
7.5 Hardy-Weinberg Equilibrium	**7.5.A** Describe the conditions under which allele and genotype frequencies will change in populations.
7.6 Evidence of Evolution	**7.6.A** Describe the types of data that provide evidence for evolution. **7.6.B** Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.
7.7 Common Ancestry	**7.7.A** Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.
7.8 Continuing Evolution	**7.8.A** Explain how evolution is an ongoing process in all living organisms.
7.9 Phylogeny	**7.9.A** Describe the types of evidence that can be used to infer an evolutionary relationship. **7.9.B** Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.
7.10 Speciation	**7.10.A** Describe the conditions under which new species may arise. **7.10.B** Describe the rate of evolution and speciation under different ecological conditions. **7.10.C** Explain the processes and mechanisms that drive speciation.
7.11 Variations in Populations	**7.11.A** Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.
7.12 Origins of Life on Earth	**7.12.A** Describe the scientific evidence that supports models of the origin of life on Earth.

Additional Resources

Unit 7 Review Video

CED Topic TikToks

Topic TikToks

Wayground Game Codes

AP Biology Exam Review

Topic 7.1 Introduction to Natural Selection

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">7.1.A Describe the causes of natural selection.</td></tr>
<tr><td>7.1.A.1: Natural selection is a major mechanism of evolution.</td><td>☐ I can describe natural selection.
☐ I can describe the causes of natural selection.</td></tr>
</table>

1. What is natural selection?
2. How does natural selection lead to evolution?
3. What are two causes of natural selection?

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">7.1.A Describe the causes of natural selection.</td></tr>
<tr><td>7.1.A.2: According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing on those favorable traits to subsequent generations</td><td>☐ I can describe Darwin's theory of natural selection.
☐ I can apply differential survival in a situation of competition for limited resources.</td></tr>
</table>

4. What is Darwin's theory of natural selection?
5. What does differential survival mean?
6. TRUE or FALSE: Favorable traits are ALWAYS favorable.
7. Why do organisms require competition for limited resources to allow for natural selection?

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">7.1.B Explain how natural selection affects populations.</td></tr>
<tr><td>7.1.B.1: Evolutionary fitness is measured by reproductive success</td><td>☐ I can explain how natural selection affects populations.
☐ I can explain how evolutionary fitness is measured.
☐ I can explain reproductive success.</td></tr>
</table>

8. How does natural selection affect populations?
9. What is evolutionary fitness?
10. How is evolutionary fitness measured?
11. What is reproductive success?
12. How does reproductive success lead to natural selection?

Evolution: The process of evolution drives the diversity and unity of life.	
7.1.B Explain how natural selection affects populations.	
7.1.B.2: Biotic and abiotic environments can fluctuate, affecting the rate and direction of evolution. Different genetic variations can be selected in each generation.	☐ I can explain ways biotic environments can affect the direction of evolution. ☐ I can explain ways biotic environments can affect the rate of evolution. ☐ I can explain ways abiotic environments can affect the direction of evolution. ☐ I can explain ways abiotic environments can affect the rate of evolution. ☐ I can describe how different genetic variations affect selection in each generation.

13. What does biotic and abiotic mean?
14. How does a biotic environment affect the direction of evolution?
15. How does an abiotic environment affect the direction of evolution?
16. How does a biotic environment affect the rate of evolution?
17. How does an abiotic environment affect the rate of evolution?
18. How does a genetic variation affect natural selection?

Topic 7.2: Natural Selection

Evolution: The process of evolution drives the diversity and unity of life.	
7.2.A Describe the importance of phenotypic variation in a population.	
7.2.A.1 Natural selection acts on phenotypic variations in populations.	☐ *I can describe the importance of phenotypic variation in a population.* ☐ *I can describe what natural selection acts on.*

1. What is phenotype?
2. How does phenotypic variation leads to differential success?
3. What does natural selection act on … PHENOTYPE or GENOTYPE?
4. What does natural selection modify … PHENOTYPE or GENOTYPE?
5. How does natural selection act on and modify different levels of genes?

Evolution: The process of evolution drives the diversity and unity of life.	
7.2.A Describe the importance of phenotypic variation in a population.	
7.2.A.2 Environments change and apply selective pressures to populations.	☐ *I can describe ways an environment applies selective pressure to a population.*

6. What are selective pressures?
7. How does an environment apply a selective pressure to a population?
8. Describe how a population changes due to an applied selective pressure.

Evolution: The process of evolution drives the diversity and unity of life.	
7.2.A Describe the importance of phenotypic variation in a population.	
7.2.A.3 Some phenotypic variations can increase or decrease the fitness of an organism in particular environments.	☐ *I can describe ways a phenotypic variation can increase fitness of an organism in a particular environment.* ☐ *I can describe ways a phenotypic variation can decrease fitness of an organism in a particular environment.*

9. Identify two examples of a phenotypic variation that increases fitness of an organism in a particular environment.
10. Identify two examples of a phenotypic variation that decreases fitness of an organism in a particular environment.

Specific Examples (NOT REQUIRED KNOWLEDGE FOR THE AP EXAM BUT APPLICATIONAL)

11. How does the MC1R gene found in the Rock Pocket Mouse population causing expression of dark colored melanin pigmentation lead to differential success on the dark lava flows?
12. How does a mutation in the cortex gene in Peppered Moths leading to darker coloration aid in their survival in polluted forests?
13. The Pitx1 gene leads to the stickleback fish developing a pelvic spine. In marine environment with predatory fish, the pelvic spine is prevalent. In the freshwater environment without predatory fish but predatory dragonfly larvae that grab the pelvic spine, it is absent. Describe the difference in the expression of the Pitx1 gene.

Evolution: The process of evolution drives the diversity and unity of life.	
7.2.B Explain how variation in molecules within cells connects to the fitness of an organism.	
7.2.B.1 Variation in the number and types of molecules within cells can provide populations a greater ability to survive and reproduce in different environments	☐ I can explain how variation in molecules within cells connects to the fitness of an organism ☐ I can explain the connection between variation in the number and types of molecules within cells to the ability of the organism to survive and reproduce in different environment. ☐ I can explain ways variation at the molecular level provides organisms with the ability to respond to environmental stimuli. ☐ I can explain ways variation in the number of molecules within cells provides organisms a selective advantage. ☐ I can explain ways variation in the types of molecules within cells provides organisms a selective advantage.

14. How can cells differ in the number and types of molecules within cells?
15. How does variation at the molecular level affect the organism's ability to respond to environmental stimuli?
16. How does this variation in number of molecules lead to a selective advantage?
17. How does this variation in types of molecules lead to a selective advantage?

Specific Examples (NOT REQUIRED KNOWLEDGE FOR THE AP EXAM BUT APPLICATIONAL)

18. In cold-weather mammals, why would do the cells in the body core have more saturated fatty acids while cells in the legs and ears have more unsaturated fatty acids?
19. How do fetal hemoglobin and adult hemoglobin differ in their oxygen affinity?
    a) Describe the need for this difference based on survival at different life stages?
20. What is the difference between chlorophyll a and chlorophyll b?

b) Plants adapted to shady environments have more chlorophyll b while others thriving in bright light rely more on chlorophyll a. How does the variation in the amount of these chlorophylls provide differential success to these different plants?

Topic 7.3: Artificial Selection

Evolution: The process of evolution drives the diversity and unity of life.	
7.3.A Explain how humans can affect diversity within a population.	
7.3.A.1 Through artificial selection, humans affect variation in other species.	☐ I can explain ways humans affect diversity within a population. ☐ I can describe artificial selection. ☐ I can describe ways artificial selection affects variation in a species.

1. What is artificial selection?
2. How does artificial selection modify the variation in a species?
3. Identify two examples of artificial selection due to humans.
    a. How has this modified the species?

Topic 7.4: Population Genetics

Evolution: The process of evolution drives the diversity and unity of life.	
7.4.A Explain how random occurrences affect the genetic makeup of a population.	
7.4.A.1 Evolution is also driven by random occurrences. I. Mutation is a random process that adds new genetic variation to a population. II. Genetic drift is a change in allele frequencies attributable to a nonselective process occurring in small populations. III. The bottleneck effect is a type of genetic drift that occurs when a population size is reduced to a small number of individuals for at least one generation. IV. The founder effect is a type of genetic drift that occurs when a population is separated from other members of the population. The frequency of genes and traits will shift based on the genes in this new founder population. V. Migration can result in gene flow (the addition or removal of alleles from a population).	☐ I can explain ways random occurrences affect the genetic makeup of a population. ☐ I can describe a mutation ☐ I can explain ways that mutations affect genetic makeup of a population. ☐ I can explain genetic drift. ☐ I can explain bottleneck effect. ☐ I can explain ways bottleneck effect affects genetic makeup of a population. ☐ I can explain founder effect. ☐ I can explain ways founder effect affects genetic makeup of a population. ☐ I can explain gene flow. ☐ I can explain ways gene flow affects genetic makeup of a population.

1. What are mutations?
2. Identify two examples of mutations that potentially could affect phenotype.
3. How do mutations affect genetic makeup of a population?
4. What is genetic drift?
5. What is the bottleneck effect?
6. How does the bottleneck effect modify genetic makeup of a population?
7. Identify one example of a population that has undergone the bottleneck effect.
8. What is the founder's effect?
9. How does the founder's effect modify genetic makeup of a population?
10. Identify one example of a population that has undergone the founder's effect.
11. What is gene flow?
12. How does gene flow modify genetic makeup of a population?
13. Identify one example of a population that has undergone gene flow.

Evolution: The process of evolution drives the diversity and unity of life.	
7.4.B Describe the role of random processes in the evolution of specific populations.	
7.4.B.1 Random processes can lead to changes in allele frequencies in a population. I. Mutations result in genetic variation, which provides phenotypes on which natural selection acts. II. Genetic drift can allow a small population to diverge from other populations of the same species. III. Gene flow between two populations prevents them from diverging into separate species.	☐ I can describe ways that mutations cause genetic variation. ☐ I can describe ways that genetic variation provides different phenotypes. ☐ I can describe ways natural selection acts on phenotypes. ☐ I can describe directional selection. ☐ I can describe stabilizing selection. ☐ I can describe disruptive selection. ☐ I can describe how genetic drift can lead to divergence. ☐ I can describe how gene flow inhibits divergence.

14. What is the effect of mutations on genetic variation?
15. How does genetic variation lead to a variation in phenotypes?
16. Identify two examples of natural selection acting on phenotypes.
17. What are the three types of selection?
    a. Identify an example of each of type of selection.
18. How does genetic drift affect a small population vs a large population?
19. How does genetic drift cause a small population to diverge from other populations of the same species?
20. How does gene flow affect a population?
21. How does gene flow affect the genetic variation between two populations of the same species?

Evolution: The process of evolution drives the diversity and unity of life.	
7.4.C Describe the change in the genetic makeup of a population over time.	
7.4.C.1 Changes in allele frequencies provide evidence for the occurrence of evolution in a population.	☐ I can describe the change in genetic makeup of a population over time. ☐ I can describe how allele frequencies provide evidence for evolution.

22. How can you measure allele frequencies changes?
23. What causes changes in allele frequencies?
24. What does a change in allele frequency provide evidence of?

Topic 7.5: Hardy-Weinberg Equilibrium

<table>
<tr><td colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</td></tr>
<tr><td colspan="2">7.5.A Describe the conditions under which allele and genotype frequencies will change in populations.</td></tr>
<tr><td>7.5.A.1 The Hardy–Weinberg Equilibrium is a model for describing and predicting allele frequencies in a non-evolving population. Conditions for a population or an allele to be in Hardy–Weinberg equilibrium are:
I. A large population size
II. No migration
III. No new mutations
IV. Random mating
V. No natural selection
These conditions are never met, but they provide a valuable null hypothesis.</td><td>☐ I can describe the conditions under which allele frequencies will change in populations.
☐ I can describe the conditions under which genotypes frequencies will change in populations.
☐ I can describe the Hardy-Weinberg Equilibrium.
☐ I can describe a population demonstrating Hardy-Weinberg Equilibrium.</td></tr>
</table>

1. What is Hardy-Weinberg equilibrium?
2. What are the five conditions that must be TRUE for Hardy-Weinberg equilibrium?
   Note: If you have not watched the "Five Fingers of Evolution" from TedEd – I highly recommend it

<table>
<tr><td colspan="2">Evolution:
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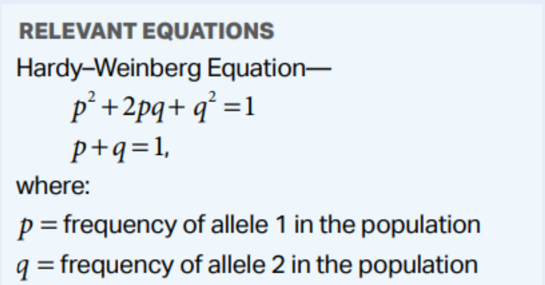
<tr><td colspan="2">7.5.A Describe the conditions under which allele and genotype frequencies will change in populations.</td></tr>
<tr><td>7.5.A.2 Allele frequencies in a nonevolving population can be calculated from genotype frequencies.

RELEVANT EQUATIONS
Hardy–Weinberg Equation—
$p^2 + 2pq + q^2 = 1$
$p + q = 1$,
where:
p = frequency of allele 1 in the population
q = frequency of allele 2 in the population</td><td>☐ I can calculate allele frequencies from genotype frequencies.
☐ I can identify the variables in Hardy-Weinberg equation.</td></tr>
</table>

3. What is allele frequency?
4. What is genotypic frequency?
5. What are the equations for Hardy-Weinberg equilibrium?
   a. Identify all the variables in the equation.

6. There are two ways to solve for the variables in the equation.
   a. Option one: Solve for the alleles
      There are three colors of snapdragons, solve for all the values if there are 100 red flowers, 800 pink flowers, and 100 white flowers.

p	q	p^2	$2pq$	q^2

   b. Option two: Solve for q^2, then solve for other values
      Flowers can either be purple (dominant) or white (recessive). Solve for all the values if 75% of the flowers are purple.

p	q	p^2	$2pq$	q^2

7. What does it mean if the allele frequency changes from one generation to the next?
8. What does it mean if the genotype frequency stays the same from one generation to the next?
9. Why are small populations more susceptible to changes in allele frequency?

Topic 7.6: Evidence of Evolution

Evolution: The process of evolution drives the diversity and unity of life.	
7.6.A Describe the types of data that provide evidence for evolution.	
7.6.A.1 Evolution is supported by scientific evidence from many disciplines (geographical, geological, physical, biochemical, and mathematical data).	☐ I can describe the types of data that provide evidence for evolution. ☐ I can use geographical data to support evolution. ☐ I can use geological data to support evolution. ☐ I can use physical data to support evolution. ☐ I can use biochemical data to support evolution. ☐ I can use mathematical data to support evolution.

1. What is biogeography?
2. How does geographical data support evolution?
    a. Provide one example geographical data.
3. How does geological data support evolution?
    a. Provide one example of geological data.
4. How does physical data support evolution?
    a. Provide one example of physical data.
5. How does biochemical data support evolution?
    a. Provide one example of biological data.
6. How does mathematical data support evolution?
    a. Provide one example of mathematical data.

Evolution: The process of evolution drives the diversity and unity of life.	
7.6.B Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.	
7.6.B.1 Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution. I. Fossils can be dated by a variety of methods. These include 1) the age of the rocks where a fossil is found; 2) the rate of decay of isotopes including carbon-14; and 3) geographical data. II. Morphological homologies, including vestigial structures, provide evidence of common ancestry	☐ I can explain ways molecular data provide evidence that organisms have changed over time. ☐ I can explain ways morphological data provide evidence that organisms have changed over time. ☐ I can explain ways geological data provide evidence that organisms have changed over time. ☐ I can date fossils using information about the age of rocks layers where it is found. ☐ I can date fossils using carbon-14 decay. ☐ I can date fossils using geographical data. ☐ I can explain how homologies provide evidence of common ancestry.

7. What are extant and extinct organisms?
8. What are fossils?
9. How can fossils be used as evidence of evolution?
10. Describe THREE ways fossils can be dated.
11. How do the rock layers allow for dating of fossils?

12. What is carbon-14 decay?
    a. How can carbon-14 decay be used to date fossils?
13. How can geographical data be used to date fossils?
14. What are homologous structures?
15. What are analogous structures?
16. What is embryology?
17. Which results from convergent evolution (not representing common ancestry)? HOMOLOGOUS or ANALOGOUS

<table>
<tr><th colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</th></tr>
<tr><td colspan="2">7.6.B Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.</td></tr>
<tr><td>7.6.B.2 A comparison of DNA nucleotide sequences and protein amino acid sequences provides evidence for evolution and common ancestry.</td><td>☐ I can compare DNA nucleotide sequences to provide evidence for evolution and common ancestry.
☐ I can compare protein amino acid sequences to provide evidence for evolution and common ancestry.</td></tr>
</table>

18. DNA and proteins can be used as evidence of evolution. Which is more accurate to determine most recent common ancestor? DNA or PROTEINS
    a. Justify your answer.
19. How do the number of differences of nucleotides or amino acids demonstrate ancestry of organisms?

Topic 7.7: Common Ancestry

<table>
<tr><th colspan="2">**Evolution:**
The process of evolution drives the diversity and unity of life.</th></tr>
<tr><td colspan="2">**7.7.A** Describe structural and functional evidence on cellular and molecular levels that provides evidence for the common ancestry of all eukaryotes.</td></tr>
<tr><td>**7.7.A.1** Structural and functional evidence indicates common ancestry of all eukaryotes. This evidence includes:
I. Membrane-bound organelles
II. Linear chromosomes
III. Genes that contain introns</td><td>☐ I can describe structural and functional evidence on the cellular level that provides evidence for the common ancestry of all eukaryotes.
☐ I can describe structural and functional evidence on the molecular level that provides evidence for the common ancestry of all eukaryotes.
☐ I can describe ways that membrane-bound organelles indicate common ancestry of all eukaryotes.
☐ I can describe ways that linear chromosomes indicate common ancestry of all eukaryotes.
☐ I can describe ways that genes containing introns indicate common ancestry of all eukaryotes.</td></tr>
</table>

1. What are membrane-bound organelles?
2. What type of cells have membrane-bound organelles? EUKARYOTIC or PROKARYOTIC
3. How did membrane-bound organelles originate?
4. How do membrane-bound organelles indicate common ancestry for all eukaryotes?
5. Describe a linear chromosome.
6. How are prokaryotic chromosomes organized?
7. How are eukaryotic chromosomes organized?
8. How do linear chromosomes indicate common ancestry for all eukaryotes?
9. What is an intron?
10. When are introns removed?
11. What type of cells have introns? EUKARYOTIC or PROKARYOTIC
12. How do genes containing introns indicate common ancestry for all eukaryotes?

Topic 7.8: Continuing Evolution

<table>
<tr><th colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</th></tr>
<tr><td colspan="2">7.8.A Explain how evolution is an ongoing process in all living organisms.</td></tr>
<tr><td>7.8.A.1 All species have evolved and continue to evolve. Examples include:
I. Genomic changes over time
II. Continuous change in the fossil record
III. Evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs
IV. Pathogens evolving and causing emergent diseases</td><td>☐ I can explain ways to show that evolution is an ongoing process in all living organisms.
☐ I can explain ways to show that population of organisms continue to evolve.
☐ I can use genomic changes over time to support the claim that all species have evolved and continue to evolve.
☐ I can use continuous change in the fossil record to support the claim that all species have evolved and continue to evolve.
☐ I can use evolution of resistance to antibiotics, pesticides, herbicides, or chemotherapy drugs to support the claim that all species have evolved and continue to evolve.
☐ I can use pathogen evolution and causation of emergent disease to support the claim that all species have evolved and continue to evolve.</td></tr>
</table>

1. What evolves? INDIVIDUALS or POPULATIONS
2. True or False: Once a population of organisms are perfect, they will cease evolving.
3. How can scientists use genomes to prove that all species continue to evolve?
4. How can scientists use fossil record to prove that all species continue to evolve?
5. What does it mean if a population of bacteria is antibiotic resistant?
6. How does a population of bacteria become antibiotic resistant?
7. How does this resistance to antibiotics support the claim that all species have evolved and continue to evolve?
   - Note this should be applicable to pesticides, herbicides, or chemotherapy drugs.
8. Why do you need to get the influenza vaccine every year?
9. How does the fact that viruses and other pathogens change over time support the claim that all species have evolved and continue to evolve?

Topic 7.9: Phylogeny

<table>
<tr><th colspan="2">Evolution:
The process of evolution drives the diversity and unity of life.</th></tr>
<tr><td colspan="2">7.9.A Describe the types of evidence that can be used to infer an evolutionary relationship.</td></tr>
<tr><td>7.9.A.1 Phylogenetic trees and cladograms show hypothetical evolutionary relationships among lineages that can be tested.</td><td>☐ I can describe the types of evidence that can be used to infer an evolutionary relationship.
☐ I can use phylogenetic trees and cladograms to show evolutionary relationships among lineages.</td></tr>
</table>

1. What type of evidence can be used to infer an evolutionary relationship?
2. Describe how to develop a phylogenetic tree.
3. Describe how to develop a cladogram.

<table>
<tr><th colspan="2">Evolution:
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<tr><td colspan="2">7.9.A Describe the types of evidence that can be used to infer an evolutionary relationship.</td></tr>
<tr><td>7.9.A.2 Phylogenetic trees show the amount of change over time calibrated by fossils or a molecular clock, whereas cladograms do not show time scale or the evolutionary difference between groups.</td><td>☐ I can compare the data provided by a phylogenetic tree and cladogram.
☐ I can contrast the data provided by a phylogenetic tree and cladogram.</td></tr>
</table>

4. What is a phylogenetic tree?
5. What is a cladogram?
6. Identify one similarity about the data presented in a phylogenetic tree and cladogram.
7. Identify one difference about the data presented in a phylogenetic tree and cladogram.

<table>
<tr><th colspan="2">Evolution:
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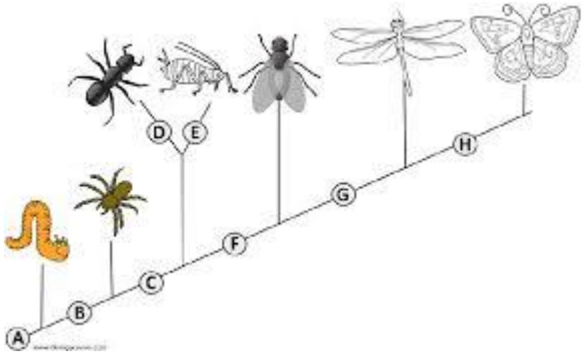
<tr><td colspan="2">7.9.A Describe the types of evidence that can be used to infer an evolutionary relationship.</td></tr>
<tr><td>7.9.A.3 Traits that are either gained or lost during evolution can be used to construct phylogenetic trees and cladograms. The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram.
I. Shared derived characters can be present in more than one lineage and indicate common ancestry. These are informative for</td><td>☐ I can use trait gained or lost during evolution to construct a phylogenetic tree or cladogram.
☐ I can describe shared characters.
☐ I can describe shared, derived characters.
☐ I can describe the outgroup.
☐ I can identify the outgroup in a phylogenetic tree or cladogram.
☐ I can describe the most accurate and reliable data for the construction of phylogenetic tree or cladogram.</td></tr>
</table>

the construction of phylogenetic trees and cladograms. II. Molecular data typically provide more accurate and reliable evidence than morphological traits in the construction of phylogenetic trees or cladograms.	

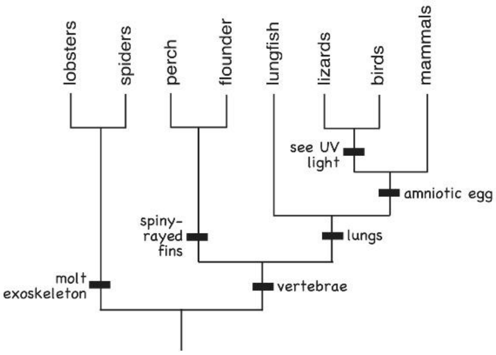
8. Where would you see a gained or lost trait on a cladogram or phylogenetic tree?
    a. For example: Using the following cladogram, identify at what point wings were gained?



9. What are shared characters?
10. What are derived characters?
11. What is an outgroup?
    a. How do you identify the outgroup on a cladogram?
12. Which if the most accurate and reliable data for construction of phylogenetic tree or cladogram? MOLECULAR DATA or MORPHOLOGICAL TRAITS
13. Justify why this type of data is the most accurate and reliable.

Evolution: The process of evolution drives the diversity and unity of life.	
7.9.B Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	
7.9.B.1 Phylogenetic trees and cladograms can be used to illustrate speciation that has occurred. The nodes on a tree represent the most recent common ancestor of any two groups or lineages.	☐ I can explain ways a phylogenetic tree and/or cladogram can be used to infer evolutionary relatedness. ☐ I can determine when speciation occurred using a phylogenetic tree and/or cladogram. ☐ I can determine the most recent common ancestor of any two groups or lineages on a phylogenetic tree and/or cladogram.

14. What does a branch point in a cladogram or phylogenetic tree represent?
15. How do you determine the most recent common ancestor on a cladogram or phylogenetic tree?
    a. For example: Identify the most recent common ancestor of lizards and mammals.


lobsters
spiders
perch
flounder
lungfish
lizards
birds
mammals
see UV light
amniotic egg
spiny-rayed fins
lungs
molt exoskeleton
vertebrae

16. In the above example, what organism is most closely related to:
    a. Spiders?
    b. Perch?
    c. Birds?

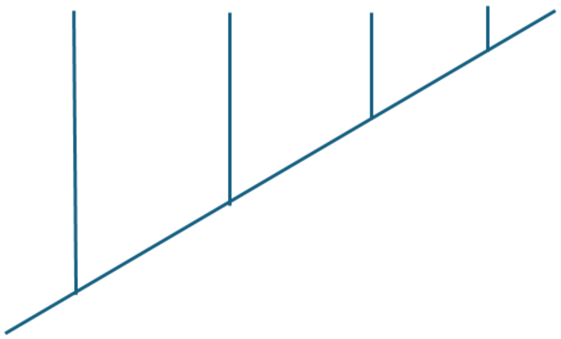
Evolution: The process of evolution drives the diversity and unity of life.	
7.9.B Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	
7.9.B.2 Phylogenetic trees and cladograms can be constructed from morphological similarities of living or fossil species and from DNA and protein sequence similarities.	☐ I can describe evidence used to construct a phylogenetic tree and/or cladogram. ☐ I can use DNA/protein sequences to develop a phylogenetic tree and/or cladogram. ☐ I can use fossil evidence to develop a phylogenetic tree and/or cladogram.

17. What evidence is used to construct a cladogram or phylogenetic tree?
18. When using molecular evidence, how do you determine if two organisms are closely related?
19. When using fossil evidence, how do you determine if two organisms are closely related?

Evolution: The process of evolution drives the diversity and unity of life.	
7.9.B Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	
7.9.B.3 Phylogenetic trees and cladograms represent hypotheses that are constantly being revised based on evidence	☐ I can use evidence to revise a phylogenetic tree and/or cladogram.

20. Using the following information, construct a cladogram:

	Horse	Donkey	Whale	Chicken	Snake
Horse	0	1	5	11	21
Donkey		0	4	10	20
Whale			0	9	18
Chicken				0	18
Snake					0



21. Modify your cladogram above based on the following information

	Horse	Donkey	Whale	Chicken	Snake
Penguin	13	12	10	3	17

Topic 7.10: Speciation

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.A Describe the conditions under which new species may arise.	
7.10.A.1 Speciation occurs when two populations become reproductively isolated from each other.	☐ I can describe the conditions under which new species may arise. ☐ I can describe speciation. ☐ I can describe the types of reproductive isolation.

1. What is speciation?
2. What causes speciation?
3. What is reproductive isolation?
4. Identify FIVE types of reproductive isolation.
5. Describe FIVE types of reproductive isolation.

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.A Describe the conditions under which new species may arise.	
7.10.A.2 The biological species concept provides a commonly used definition of a species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring.	☐ I can describe the biological species concept. ☐ I can determine whether two organisms are from the same species.

6. What is the biological species concept?
7. How can you determine if two organisms are from the same species according to the biological species concept?

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.B Describe the rate of evolution and speciation under different ecological conditions.	
7.10.B.1 Punctuated equilibrium is when evolution occurs rapidly after a long period of stasis. Gradualism is when evolution occurs slowly over hundreds of thousands or millions of years.	☐ I can describe the rate of evolution and speciation under different ecological conditions. ☐ I can describe punctuated equilibrium. ☐ I can describe gradualism.

8. What is punctuated equilibrium?
    a. Identify an example of an organism that underwent punctuated equilibrium.
9. What is gradualism?
    a. Identify an example of an organism that underwent gradualism.

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.B Describe the rate of evolution and speciation under different ecological conditions.	
7.10.B.2 Divergent evolution occurs when adaptation to new habitats results in phenotypic diversification. Speciation rates can be especially rapid during times of adaptive radiation as new habitats become available	☐ I can describe divergent evolution. ☐ I can describe the effect of adaptive radiation on speciation rates.

10. What is divergent evolution?
    a. What term do we use when two organisms have similar characteristics due to divergent evolution?
11. What is adaptive radiation?
12. What is the effect of adaptive radiation on speciation rates?

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.B Describe the rate of evolution and speciation under different ecological conditions.	
7.10.B.3 Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species.	☐ I can explain convergent evolution. ☐ I can explain ways selective pressures result in similar phenotypic adaptations in different populations.

13. What is convergent evolution?
14. Identify two examples of organisms that demonstrate convergent evolution.
15. How do selective pressures result in similar phenotypic adaptations?

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.C Explain the processes and mechanisms that drive speciation.	
7.10.C.1 Sympatric speciation occurs in populations with geographic overlap. Allopatric speciation occurs in populations that are geographically isolated.	☐ I can explain the processes that drive speciation. ☐ I can explain the mechanisms that drive speciation. ☐ I can describe the results of speciation. ☐ I can describe sympatric speciation. ☐ I can describe allopatric speciation.

16. What are the results of speciation?
17. What is sympatric speciation?
18. What mechanisms lead to speciation in sympatric speciation?
19. What is allopatric speciation?
20. What mechanisms lead to speciation in allopatric speciation?

Evolution: The process of evolution drives the diversity and unity of life.	
7.10.C Explain the processes and mechanisms that drive speciation.	
7.10.C.2 Various pre-zygotic and post-zygotic mechanisms can maintain reproductive isolation and prevent gene flow between populations.	☐ I can identify prezygotic barriers. ☐ I can describe habitat/ecological isolation. ☐ I can describe temporal isolation. ☐ I can describe behavioral isolation. ☐ I can describe gametic isolation. ☐ I can describe geographical isolation. ☐ I can identify postzygotic barriers. ☐ I can describe hybrid breakdown. ☐ I can describe reduced hybrid viability. ☐ I can describe reduced hybrid fertility. ☐ I can describe ways that reproductive barriers cause speciation.

21. What is the difference between pre- and post- zygotic reproductive barriers?
22. Using the following chart, describe the types of pre- and post- zygotic reproductive barriers with examples.

Prezygotic Reproductive Barriers		
Reproductive Isolation Type	Description	Example
Habitat/Ecological Isolation		
Temporal Isolation		
Behavioral Isolation		
Gametic Isolation		
Geographical Isolation		
Postzygotic Reproductive Barriers		
Reproductive Isolation Type	Description	Example
Hybrid Breakdown		
Reduced Hybrid Viability		
Reduced Hybrid Fertility		

23. How does reproductive isolation lead to speciation?
24. What three potential results occur when two species come in contact in the hybrid zone?

Topic 7.11: Variations in Populations

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
7.11.A Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.	
7.11.A.1 The level of variation in a population affects population dynamics. I. The ability of a population to respond to changes in the environment is influenced by genetic diversity. Species and populations with little genetic diversity are at risk of decline or extinction. II. Genetically diverse populations are more resilient to environmental perturbation because they are more likely to contain individuals that can withstand the environmental pressure. III. Alleles that are adaptive in one environmental condition may be deleterious in another because of different selective pressures.	☐ I can explain ways the genetic diversity of a species affects its ability to withstand environmental pressures. ☐ I can explain ways the genetic diversity of a population affects its ability to withstand environmental pressures. ☐ I can explain why a species/population with little genetic diversity are at risk of decline or extinction. ☐ I can predict a population's ability to respond to changes in the environment based on population diversity. ☐ I can describe the advantage of generic diversity in times of environmental perturbation. ☐ I can explain ways alleles can affect individuals differently in different environments.

1. What is genetic diversity?
2. Why are populations with little genetic diversity at risk of decline or extinction?
3. If a population is more genetically diverse, how do they respond to environmental changes?
4. What is the advantage of a population being genetically diverse?
5. True or False: Alleles that are helpful in one environment will be helpful in another environment.
6. Why do allele affect individuals differently in different environments?

AP Biology Exam Review

Topic 7.12: Origins of Life on Earth

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">7.12.A Describe the scientific evidence that supports models of the origin of life on Earth.</td></tr>
<tr><td>7.12.A.1 The origin of life on Earth is supported by scientific evidence.
I. Geological evidence reinforces models of the origin of life on Earth.
II. Earth formed approximately 4.6 billion years ago (bya). The environment was too hostile for life until about 3.9 bya, and the earliest fossil evidence for life dates to 3.5 bya. Taken together, this evidence provides a plausible range of dates for the origin of life.</td><td>☐ I can describe the scientific evidence that provides support for models of the origin of life on Earth.
☐ I can use geological evidence to support the model of the origin of life on Earth.
☐ I can identify approximately when Earth was formed.
☐ I can identify approximately when the environment on Earth was no longer considered hostile for life.
☐ I can identify approximately when the earliest fossil evidence for life was dated to.
☐</td></tr>
</table>

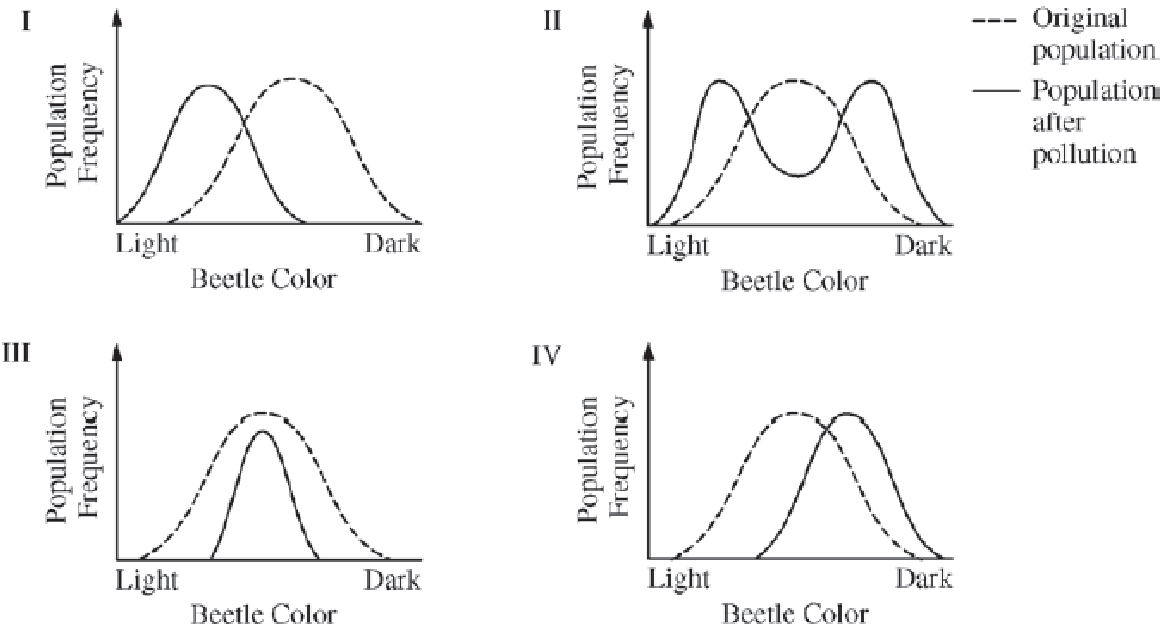
1. What geological evidence provide support for the origin of Earth?
2. Approximately when did the Earth form?
3. Approximately when was Earth no longer hostile for life?
4. Approximately when does the earliest fossil date?

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">7.12.A Describe the scientific evidence that supports models of the origin of life on Earth.</td></tr>
<tr><td>7.12.A.2 The RNA world hypothesis proposes that RNA could have been the earliest genetic material. There are three assumptions:
I. At some point in time, genetic continuity was assured by the replication of RNA.
II. Base-pairing is necessary for replication.
III. Genetically encoded proteins were not involved as catalysts.</td><td>☐ I can describe the RNA World Hypothesis.</td></tr>
</table>

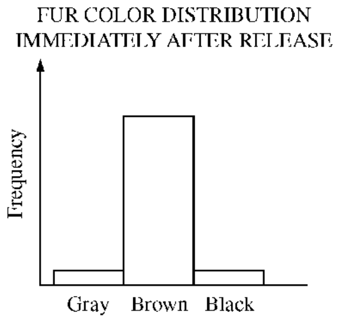
5. What is the RNA World Hypothesis?
6. Identify three supports for the RNA World Hypothesis.
7. What are ribozymes?
8. How do ribozymes confirm the RNA hypothesis?
9. Describe the base pairing needed for replication.
10. TRUE or FALSE: Genetically encoded proteins were involved as catalysts.

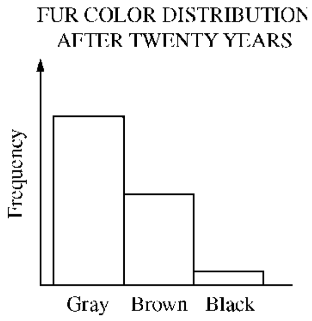
Multiple Choice Practice

1. In a hypothetical population of beetles, there is a wide variety of color, matching the range of coloration of the tree trunks on which the beetles hide from predators. The graphs below illustrate four possible changes to the beetle population as a result of a change in the environment due to pollution that darkened the tree trunks.



   Which of the following includes the most likely change in the coloration of the beetle population after pollution and a correct rationale for the change?
   a. The coloration range shifted toward more light-colored beetles, as in diagram I. The pollution helped the predators find the darkened tree trunks.
   b. The coloration in the population split into two extremes, as in diagram II. Both the lighter-colored and the darker-colored beetles were able to hide on the darker tree trunks.
   c. The coloration range became narrower, as in diagram III. The predators selected beetles at the color extremes.
   d. The coloration in the population shifted toward more darker-colored beetles, as in diagram IV. The lighter-colored beetles were found more easily by the predators than were the darker-colored beetles.
2. A group of mice was released into a large field to which no other mice had access. Immediately after the release, a representative sample of the mice was captured, and the fur color of each individual in the sample was observed and recorded. The mice were then returned to the field. After twenty years, another representative sample of the mice was captured, and the fur color of each individual in the sample was again recorded. Which of the following best explains the change in the frequency distribution of fur color phenotypes in the mouse population, as shown in the figures above?





a. The allele for gray fur color is unstable, and over twenty years most of those alleles mutated to become alleles for black fur.
b. The field was composed primarily of light-colored soil and little vegetation, affording gray mice protection from predators.
c. Sexual selection led to increased mating frequency of black and brown versus gray and brown.
d. The gray mice were hardest to capture and so were underrepresented in the twenty-year sample.

Use the following information to answer question 3:

The following figures display data collected while studying a family, some members of which have sickle-cell disease—a rare genetic disorder caused by a mutation in the hemoglobin beta gene (HBB). There are at least two alleles of the HBB gene: the HbA allele encodes wild-type hemoglobin and the HbS allele encodes the sickle-cell form of hemoglobin. Genetic testing provided insight into the inheritance pattern for sickle-cell disease.

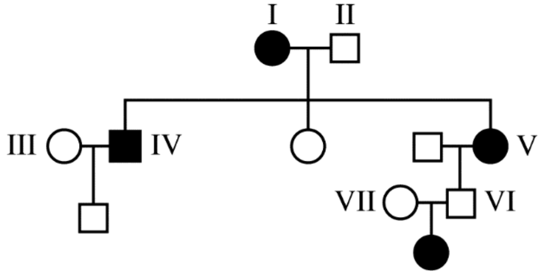
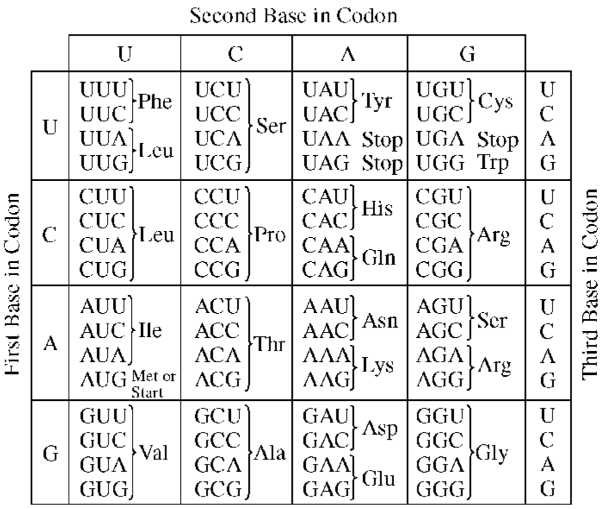


Figure 1. Pedigree of a family with affected individuals. Squares represent males, circles represent females, shaded symbols represent individuals with sickle-cell disease.

5' CTG ACT CCT GAG GAG AAG TCT 3'	Non-template Strand
3' GAC TGA GGA CTC CTC TTC AGA 5'	Template Strand

Figure 2. A portion of the DNA sequence from the wild-type hemoglobin allele (HbA) that codes for normal hemoglobin.



First Base in Codon	Second Base in Codon: U	C	A	G	Third Base in Codon
U	UUU Phe UUC Phe UUA Leu UUG Leu	UCU Ser UCC Ser UCA Ser UCG Ser	UAU Tyr UAC Tyr UAA Stop UAG Stop	UGU Cys UGC Cys UGA Stop UGG Trp	U C A G
C	CUU Leu CUC Leu CUA Leu CUG Leu	CCU Pro CCC Pro CCA Pro CCG Pro	CAU His CAC His CAA Gln CAG Gln	CGU Arg CGC Arg CGA Arg CGG Arg	U C A G
A	AUU Ile AUC Ile AUA Ile AUG Met or Start	ACU Thr ACC Thr ACA Thr ACG Thr	AAU Asn AAC Asn AAA Lys AAG Lys	AGU Ser AGC Ser AGA Arg AGG Arg	U C A G
G	GUU Val GUC Val GUA Val GUG Val	GCU Ala GCC Ala GCA Ala GCG Ala	GAU Asp GAC Asp GAA Glu GAG Glu	GGU Gly GGC Gly GGA Gly GGG Gly	U C A G

Figure 3. Codon table showing nucleotide sequences for each amino acid.

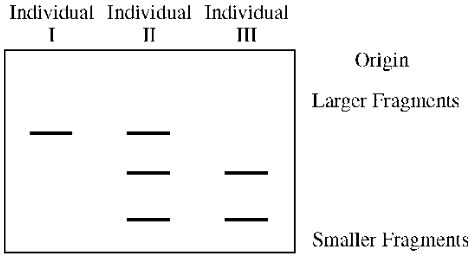
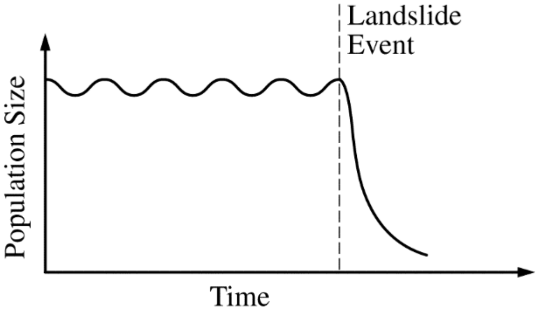


Figure 4. Image of a gel following electrophoretic separation of DNA fragments of the HBB gene from three individuals in the pedigree in Figure 1.

3. Possessing a single copy of the HbS allele has been shown to provide some resistance to infection by Plasmodium falciparum, the parasite that causes malaria. Which of the following individuals represented in the pedigree would have the greatest selective advantage in an area where malaria is common?
   - a. I
   - b. II
   - c. III
   - d. V



4. Undersea landslides can disrupt marine habitats by burying organisms that live on the ocean floor. The graph above shows the size of a population of a certain organism that lives on the ocean floor. The population was affected by a recent landslide at the time indicated on the graph. Which of the following best predicts how the population will be affected by the landslide?
   - a. The surviving organisms will evolve into a new species.
   - b. The reduced population will likely have allelic frequencies that are different from the initial population.
   - c. The population will adapt to deeper waters to avoid future landslides.
   - d. The reduced population will have a greater number of different genes than the initial population.
5. The data below demonstrate the frequency of tasters and non-tasters of a certain compound in four isolated populations that are in Hardy-Weinberg equilibrium. The allele for non-tasters is recessive. In which population is the frequency of the recessive allele highest?

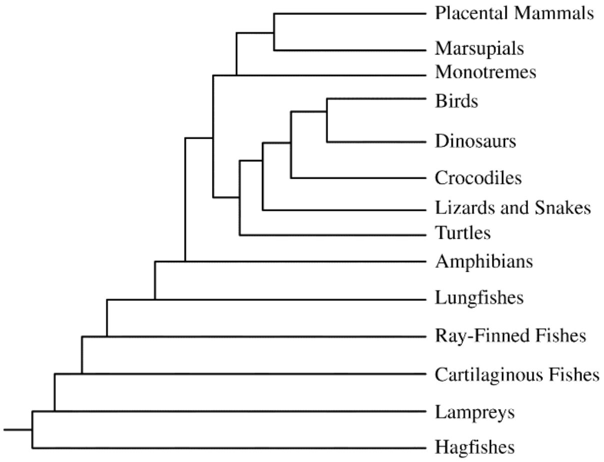
Letter Choice	Populations	Tasters	Non-tasters	Size of Population
A	1	110	32	142
B	2	8,235	4,328	12,563
C	3	215	500	715
D	4	11,489	2,596	14,085

6. Ellis-van Creveld syndrome is a recessive genetic disorder that includes the characteristics of short stature and extra fingers or toes. In the general population, this syndrome occurs in approximately 1 in 150,000 live births. In a particular isolated population, however, the incidence of this syndrome among live births is 1 in 500.

   Assume that both the isolated population and the general population are in Hardy-Weinberg equilibrium with respect to this syndrome. Which of the following best describes the difference between the frequency of the allele that causes the syndrome in the general population and the frequency of the allele in the isolated population?
   a. The frequency of the Ellis-van Creveld allele is 0.002 in the isolated population and 0.0000066 in the general population, which suggests that selection for this trait is occurring in both populations.
   b. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, showing that the rate of genetic mutation is highest among individuals in the isolated population.
   c. The frequency of the Ellis-van Creveld allele is 0.002 in the isolated population and 0.0000066 in the general population, which demonstrates gametic incompatibility between the populations.
   d. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, which suggests that genetic drift has occurred in the isolated population.

7. To determine the evolutionary history and relationships among organisms, scientists gather evidence from a wide variety of sources including paleontology, embryology, morphology, behavior, and molecular biology. A phylogenetic tree of vertebrates is shown.

   Which of the following statements is most consistent with the phylogenetic tree shown?

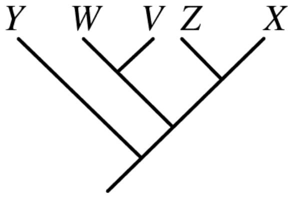


   a. Birds and turtles evolved their own means of gas exchange independently of the other vertebrates.
   b. Mammals are most closely related to birds because they share a direct common ancestor.
   c. The common ancestor of reptiles, birds, and mammals produced amniotic eggs.
   d. Crocodiles are direct descendants of ray-finned fishes since they live in the same environment.

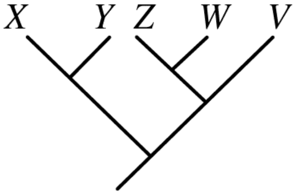
8. Data regarding the presence (+) or absence (-) of five derived traits in several different species are shown in the table below.

	Trait				
Species	1	2	3	4	5
V	+	+	+	-	-
W	+	+	-	-	-
X	+	-	-	-	-
Y	-	-	-	-	-
Z	+	-	-	-	+

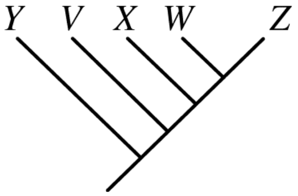
Which of the following cladograms provides the simplest and most accurate representation of the data in the table?



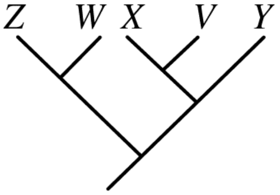
a.



b.



c.



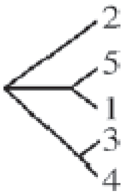
d.

9. Five new species of bacteria were discovered in Antarctic ice core samples. The nucleotide (base) sequences of rRNA subunits were determined for the new species. The table below shows the number of nucleotide differences between the species.

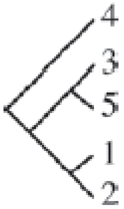
NUCLEOTIDE DIFFERENCES

Species	1	2	3	4	5
1	–	3	19	18	27
2		–	19	18	26
3			–	1	27
4				–	27
5					–

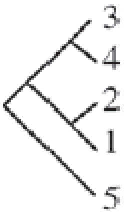
Which of the following phylogenetic trees is most consistent with the data?



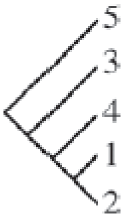
a.



b.



c.



d.

10. The apple maggot fly, *Rhagoletis pomonella*, is native to North America and originally fed on fruit of the wild hawthorn. Since the mid-1800s, a population of flies has emerged that instead feed on domesticated apples. Apple maggot flies typically mate on or near the fruit of their host plants. Many varieties of apples ripen three to four weeks before the hawthorn fruits do.
The different fruit preferences of the two fly populations will most likely have which of the following effects?
    a. The flies that eat hawthorn fruit will increase in number, while the flies that eat apples will decrease in number because of the use of insecticides on apple trees.
    b. The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.
    c. The ability to survive on a diet of two different fruits will help the flies learn to eat many more types of fruit.
    d. The flies that eat hawthorn fruit will lay some of their eggs on the earlier ripening apples to minimize competition among the larvae.

Use the following information to answer questions 13 – 15:

Rhagoletis pomonella is a parasitic fly native to North America that infests fruit trees. The female fly lays her eggs in the fruit. The larvae hatch and burrow through the developing fruit. The next year, the adult flies emerge.

Prior to the European colonization of North America, the major host of *Rhagoletis* was a native species of hawthorn, *Crataegus marshallii.* The domestic apple tree, *Malus domestica*, is not native to North America, but was imported by European settlers in the late 1700s and early 1800s.

When apple trees were first imported into North America, there was no evidence that Rhagoletis could use them as hosts. Apples set fruit earlier in the season and develop faster, where hawthorns set later and develop more slowly.

Recent analysis of *Rhagoletis* populations has shown that two distinct populations of flies have evolved from the original ancestral population of flies that were parasitic on hawthorns. One population infests only apple trees, and the other infests only hawthorns. The life cycles of both fly populations are coordinated with those of their host trees. The flies of each population apparently can distinguish and select mates with similar host preferences and reject mates from the population specific to the other host tree. There is very little hybridization (only about 5 percent) between the two groups.

13. The divergence between the two populations of Rhagoletis must have occurred very rapidly because
    a. the apple tree was imported into North America with European settlement approximately 200 years ago
    b. flies were imported into North America with European settlement approximately 200 years ago
    c. long-distance rail transport of fruit increased only after the American Civil War (1861–1865)
    d. heavy use of gunpowder during the American Civil War (1861–1865) led to increased mutation rates in many natural populations of plants and animals

14. Initially, which of the following isolating mechanisms is likely to have been the most important in preventing gene flow between the two populations of *Rhagoletis*?
    a. Gamete incompatibility
    b. Temporal isolation
    c. Mechanical isolation
    d. Reduced hybrid viability

15. Matings between individuals from the two populations of *Rhagoletis* produce hybrid flies that appear to be healthy and have normal life spans. The eggs laid by these hybrid flies, however, hatch less often than those of flies from either of the two populations. What isolating mechanism seems to be important in this hybrid population?
    a. Prezygotic isolation
    b. Mechanical isolation
    c. Reduced hybrid fertility
    d. Habitat isolation

16. A group of students summarized information on five great extinction events.

Mass Extinction	**Time of Extinction**	**Organisms Greatly Reduced or Made Extinct**
End of the Ordovician period	443 million years ago	Trilobites, brachiopods, echinoderms, and corals
End of the Devonian period	354 million years ago	Marine families on tropical reefs, corals, brachiopods, and bivalves
End of the Permian period	248 million years ago	Trilobites, mollusks, brachiopods, and many vertebrates
End of the Triassic period	206 million years ago	Mollusks, sponges, marine vertebrates, and large amphibians
End of the Cretaceous period	65 million years ago	Ammonites, dinosaurs, brachiopods, bivalves, and echinoderms

The students are sampling a site in search of fossils from the Devonian period. Based on the chart, which of the following would be the most reasonable plan for the students to follow?
    a. Searching horizontal rock layers in any class of rock and try to find those that contain the greatest number of fossils
    b. Collecting fossils from rock layers deposited prior to the Permian period that contain some early vertebrate bones
    c. Looking in sedimentary layers next to bodies of water in order to find marine fossils of bivalves and trilobites
    d. Using relative dating techniques to determine the geological ages of the fossils found so they can calculate the rate of speciation of early organisms

17. By discharging electric sparks into a laboratory chamber atmosphere that consisted of water vapor, hydrogen gas, methane, and ammonia, Stanley Miller obtained data that showed that a number of organic molecules, including many amino acids, could be synthesized. Miller was attempting to model early Earth conditions as understood in the 1950s. The results of Miller's experiments best support which of the following hypotheses?
    a. The molecules essential to life today did not exist at the time Earth was first formed.
    b. The molecules essential to life today could not have been carried to the primordial Earth by a comet or meteorite.
    c. The molecules essential to life today could have formed under early Earth conditions.
    d. The molecules essential to life today were initially self-replicating proteins that were synthesized approximately four billion years ago.

18. Which of the following best explains the process of natural selection?
    a. individuals with less favorable phenotypes are more likely to survive and produce less offspring, thus modifying traits for subsequent generations
    b. individuals with more favorable phenotypes are more likely to survive and produce less offspring, thus modifying traits for subsequent generations
    c. individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations
    d. individuals with less favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations

19. Natural selection acts on
    a. phenotype
    b. genotype
    c. gene expression
    d. reproduction

20. Which of the following best explains convergent evolution?
    a. different selective pressures result in similar phenotypic adaptations in different populations or species
    b. similar selective pressures result in similar phenotypic adaptations in different populations or species
    c. similar selective pressures result in different phenotypic adaptations in a population or species
    d. different selective pressures result in similar phenotypic adaptations in a populations or species

21. Which of the following is the cause of genetic variation?
    a. crossing over
    b. independent assortment
    c. random fertilization
    d. mutations

22. Which of the following describes why bottleneck effect is harmful to genetic diversity?
    a. the reduction in population size could lead to fixation of an allele
    b. the reduction in population size could result in a change in allele frequency
    c. the reduction in population size could cause a change in genotype frequency
    d. the reduction in population size could inhibit reproductive events

23. Which of the following describes why the founder's effect results in an increase of differences between populations of the same species?
    a. presence of genetic drift
    b. absence of gene flow
    c. addition of harmful alleles
    d. removal of reproductive barriers

24. Which of the following is a condition that must be met for a population to be in Hardy-Weinberg equilibrium?
    a. small population size
    b. nonrandom mating
    c. absence of selection
    d. presence of migration

25. If the recessive allele frequency is 0.4, what is the genotypic frequency of the heterozygous individual?
    a. 0.16
    b. 0.24
    c. 0.36
    d. 0.48

26. Which of the following describes a population most susceptible to random environmental impact?
    a. small populations
    b. large populations

27. Which of the following is NOT a method to date fossils?
    a. DNA sequencing
    b. age of rocks where a fossil is found
    c. rate of decay of isotopes including carbon-14
    d. geographical data

28. Which of the following does provides evidence for evolution and common ancestry?
    a. analogous structures
    b. homologous structures

29. Which of the following does NOT indicate common ancestry of all eukaryotes?
    a. membrane-bound organelles
    b. linear chromosomes
    c. genes that contain introns
    d. presence of chloroplasts

30. Which of the following describes why single HIV drugs are ineffective over time?
    a. Reverse transcriptase binds to HIV drugs inhibiting drug effectiveness
    b. Mutations in the HIV genome leads to reproductive success
    c. HIV engulfs drugs through phagocytosis and digests them in the lysosome
    d. Drugs decompose prior to inhibit HIV genome from replication

31. Which of the following best represents the outgroup in a cladogram?
    a. least closely related to the remainder of the organisms in the cladogram
    b. most closely related to the remainder of the organisms in the cladogram
    c. organism found on the farthest branch point from the common ancestor
    d. organism found on the closest branch point to the organism of interest

32. Which type of data provides the most accurate and reliable evidence to construct phylogenetic trees or cladograms?
    a. morphological
    b. molecular
    c. biogeographical
    d. temporal

33. Which of the following describes the biological species concept?
    a. group capable of interbreeding and exchanging genetic information to produce feeble, fertile offspring
    b. group capable of interbreeding and exchanging genetic information to produce feeble, sterile offspring
    c. group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring
    d. group capable of interbreeding and exchanging genetic information to produce viable, sterile offspring

34. Which of the following contrasts punctuated equilibrium and gradualism?
    a. punctuated equilibrium occurs slowly over hundreds of thousands of years while gradualism results in rapid evolution after long period of stasis
    b. punctuated equilibrium results from allopatric speciation while gradualism results from sympatric speciation
    c. punctuated equilibrium results from sympatric speciation while gradualism results from allopatric speciation
    d. punctuated equilibrium results in rapid evolution after long period of stasis while gradualism occurs slowly over hundreds of thousands of years

35. Which of the following types of reproductive barriers involves inhibiting reproduction due to a different mating season?
    a. behavioral
    b. temporal
    c. gametic
    d. ecological

36. Which of the following types of reproductive barriers involves inhibiting reproduction due to a difference in mating rituals?
    a. behavioral
    b. temporal
    c. gametic
    d. ecological

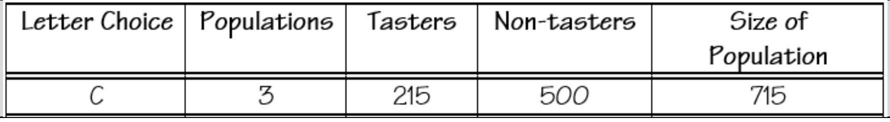
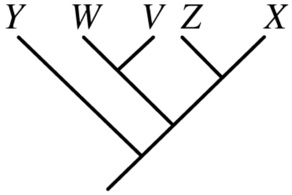
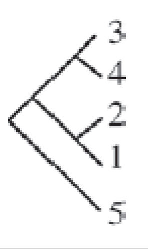
37. Which of the following describes ways that the amount of diversity in an ecosystem can be determined?
    a. rate of speciation and rate of extinction
    b. rate of reproductive and rate of speciation
    c. rate of extinction and rate of immigration
    d. rate of reproduction and rate of immigration

38. Which of the following provides a viable option as to the origin of organic molecules?
    a. biotic synthesis
    b. transported to Earth by meteorite
    c. hydrolysis of inorganic molecules
    d. Earth colliding with other planets

39. Which of the following was the earliest genetic material?
    a. DNA
    b. RNA
    c. Proteins
    d. Carbohydrate

AP Biology Exam Review

Multiple Choice Key

<table>
<tr><th>Question</th><th>Correct Answer</th><th>Unit/Topic</th><th>Source</th></tr>
<tr><td>1</td><td>D. The coloration in the population shifted toward more darker-colored beetles, as in diagram IV. The lighter- colored beetles were found more easily by the predators than were the darker-colored beetles.</td><td>7.2</td><td>2012 CED #21</td></tr>
<tr><td>2</td><td>B. The field was composed primarily of light-colored soil and little vegetation, affording gray mice protection from predators.</td><td>7.2</td><td>2012 #23</td></tr>
<tr><td>3</td><td>B. II</td><td>7.11*
(8.7*)</td><td>2013 #51</td></tr>
<tr><td>4</td><td>B. The reduced population will likely have allelic frequencies that are different from the initial population.</td><td>7.4</td><td>2013 #4</td></tr>
<tr><td>5</td><td>
<table>
<tr><th>Letter Choice</th><th>Populations</th><th>Tasters</th><th>Non-tasters</th><th>Size of Population</th></tr>
<tr><td>C</td><td>3</td><td>215</td><td>500</td><td>715</td></tr>
</table></td><td>7.5*</td><td>2013 #40</td></tr>
<tr><td>6</td><td>D. The frequency of the Ellis-van Creveld allele is 0.0447 in the isolated population and 0.0026 in the general population, which suggests that genetic drift has occurred in the isolated population.</td><td>7.5</td><td>2013 #53</td></tr>
<tr><td>9</td><td>C. The common ancestor of reptiles, birds, and mammals produced amniotic eggs.</td><td>7.9</td><td>2013 #32</td></tr>
<tr><td>10</td><td>A. 
</td><td>7.9</td><td>2013 #18</td></tr>
<tr><td>11</td><td>C. 
</td><td>7.9</td><td>2012 CED #18</td></tr>
<tr><td>12</td><td>B. The single fly species will evolve into two distinct species because of the lack of gene flow between the two populations.</td><td>7.10</td><td>2020 CED #13</td></tr>
<tr><td>13</td><td>A. the apple tree was imported into North America with European settlement approximately 200 years ago</td><td>7.10</td><td>2013 #20</td></tr>
<tr><td>14</td><td>B. Temporal isolation</td><td>7.10</td><td>2013 #21</td></tr>
<tr><td>15</td><td>C. Reduced hybrid fertility</td><td>7.10</td><td>2013 #22</td></tr>
<tr><td>16</td><td>B. Collecting fossils from rock layers deposited prior to the Permian period that contain some early vertebrate bones</td><td>8.7
(I disagree CB)</td><td>2012 CED #37</td></tr>
<tr><td>17</td><td>C. The molecules essential to life today could have formed under early Earth conditions.</td><td>7.12</td><td>2012 CED #1</td></tr>
</table>

18	C. individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations	7.1	Self
19	A. phenotype	7.2	Self
20	B. similar selective pressures result in similar phenotypic adaptations in different populations or species	7.10	Self
21	D. mutations	7.4	Self
22	A. the reduction in population size could lead to fixation of an allele	7.4	Self
23	B. absence of gene flow	7.4	Self
24	C. absence of selection	7.5	Self
25	D. 0.48	7.5	Self
26	A. small populations	7.4	Self
27	A. DNA sequencing	7.6	Self
28	B. homologous structures	7.6	Self
29	D. presence of chloroplasts	7.7	Self
30	B. Mutations in the HIV genome leads to reproductive success	7.8	Self
31	A. least closely related to the remainder of the organisms in the cladogram	7.9	Self
32	B. molecular	7.9	Self
33	C. group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring	7.10	Self
34	D. punctuated equilibrium results in rapid evolution after long period of stasis while gradualism occurs slowly over hundreds of thousands of years	7.10	Self
35	B. temporal	7.10	Self
36	A. behavioral	7.10	Self
37	A. rate of speciation and rate of extinction		Self
38	B. transported to Earth by meteorite		Self
39	B. RNA	7.12	Self

* no longer in AP Classroom so might be "out of scope"

Multiple Choice Explanations

Q		Explanation:
1	A	If the beetles were lighter, they would be more easily seen on the darkened tree trunks and less likely to survive to pass on their traits. This option is incorrect. The population of beetles after pollution would not have shifted to a more light-colored beetle as indicated in diagram I because the tree trunks would have been darker, and the lighter colored beetles would have been eaten by predators more easily since they were light and the trees were dark. The suggestion that the predators would find the darker tree trunks more easily is irrelevant. (CollegeBoard)
	B	The darker phenotypes were able to camouflage, but the lighter phenotypes will be more likely seen and eaten by predators. This option is incorrect. After the pollution the coloration could not have split into two groups because the lighter colored beetles would not have been able to hide on the darker tree trunks and thus would have been preyed upon. (CollegeBoard)
	C	As the tree trunks got darker, the darker phenotype would be more likely to camouflage so there would not be a decrease in the dark phenotypes as it is a favorable trait. This option is incorrect. The coloration range after pollution would not have become narrower, as in diagram III, because predators were selecting those light-colored beetles that were distinguishable on the darker tree trunks. (CollegeBoard)
	D	**After pollution, the tree trunks were darker. The beetles that had darker phenotypes were able to camouflage and less likely to be eaten by predators. Over time, a directional selection should be observed to darker phenotypes.** **This option is correct because it illustrates the change in the population that would occur with selection against the lighter colored beetles. The student is asked to justify and explain the process of biological evolution in this question. A change in coloration of the beetle population after pollution is shown in diagram IV because the original beetles (lighter colored beetles) were eaten by predators, and the darker colored beetles would have survived. (CollegeBoard)**
2	A	There is a decrease in the frequency of the black phenotype.
	B	**There is a directional selection observed. The gray phenotype was more favorable leading to an increase in surviving. If the environment was light, the gray mouse would be more likely to camouflage and not be caught by the predators.**
	C	Sexual selection increased mating of black and brown would lead to an increase in black and brown individuals, but both of these phenotypes decreased in frequency.
	D	The gray phenotype has the highest frequency and could not be classified as "underrepresented"
3	A	Using the pedigree, we can determine that individual I has a genotype of HbS HbS. They will not have a selective advantage as they are affected by sickle cell disease.
	B	**According to the prompt, an individual that is heterozygous (HbA HbS) will have a selective advantage. Using the pedigree, we can determine individual II is heterozygous because they are unaffected but have affected offspring.**
	C	Using the pedigree, we can determine that individual III has a genotype of HbA HbA. They do not have a HbS allele to provide a selective advantage.

	D	Using the pedigree, we can determine that individual I has a genotype of HbS HbS. They will not have a selective advantage as they are affected by sickle cell disease.
4	A	A new species results from an absence of gene flow. The landslide did not cause a restriction to reproduction between organisms.
	B	**The landslide event describes a bottleneck situation. During a bottleneck, there is a rapid decrease in the population and the remaining individuals do not represent the original population (the allele frequencies are different).**
	C	Adaptations are the result of traits that already exist to be more favorable. So, the population will not decide to bury deeper because of this landslide.
	D	This is not logical. How can you reduce the population but have more of different genes?
5	A	$32/142 = q^2 = 0.23$ $q = \sqrt{0.23} = 0.47$
	B	$4328/12563 = q^2 = 0.34$ $q = \sqrt{0.34} = 0.59$
	C	**$500/715 = q^2 = 0.69$ $q = \sqrt{0.69} = 0.84$ ← This is the largest number for the recessive allele frequency**
	D	$2596/14085 = q^2 = 0.18$ $q = \sqrt{0.18} = 0.43$
6	A	general population: $1/150{,}000 = q^2 = 0.0000067$ isolated population: $1/500 = q^2 = 0.002$ This answer choice is the genotypic frequency NOT the allele frequency
	B	general population: $1/150{,}000 = q^2 = 0.0000067$ $q = \sqrt{0.0000067} = 0.0026$ isolated population: $1/500 = q^2 = 0.002$ $q = \sqrt{0.002} = 0.0447$ We do not have any data to support that the mutations occurred after the isolated population was isolated.
	C	general population: $1/150{,}000 = q^2 = 0.0000067$ isolated population: $1/500 = q^2 = 0.002$ This answer choice is the genotypic frequency NOT the allele frequency
	D	**general population: $1/150{,}000 = q^2 = 0.0000067$ $q = \sqrt{0.0000067} = 0.0026$** **isolated population: $1/500 = q^2 = 0.002$ $q = \sqrt{0.002} = 0.0447$** **Genetic drift (specifically founders effect) the population is isolated and has a different allele frequency than the original population.**
7	A	Birds and turtles are not on a similar branch to represent this similarity of their gas exchange processes.
	B	Mammals and birds have 4 branch points between them demonstrating that they do not share a direct common ancestor.
	C	**All of these organisms produce amniotic eggs, so it must have originated in the common ancestor.**
	D	The crocodile is 6 branches away from the ray-finned fishes. The crocodiles are not closely related to the ray-finned fishes.
8	A	**Y has no traits in common with the other organisms demonstrating its "outgroup" and first branched off status. All of the other organisms have trait 1, so that trait was gained after Y branched off. V and W share trait 2 in common so they will be branched together. X and Z share trait 1 so they will be branched together.**
	B	Y has no traits in common with the other organisms and should not be on a branch point with X as X has a trait in common with the other organisms.
	C	V has 3 traits, X has 1 trait, W has 2 traits, and Z has 2 traits. This tree does not represent relatedness of organisms as their shared traits should allow them to be grouped together.
	D	W and V should be branched together as they both share trait 2.

9	A	Species 5 is an outgroup as it has 26 or 27 nucleotide differences with each of the other species. This option is incorrect. The nucleotide differences between species 5 and 1 in the data set are high and do not represent a close relationship (CollegeBoard)
	B	Species 5 is an outgroup as it has 26 or 27 nucleotide differences with each of the other species. This option is incorrect. Even though the nucleotide differences between species 5 and 3 in the data set show a close relationship, species 3 and 4 have fewer differences and thus are closer in their evolutionary history (CollegeBoard)
	C	**There is 1 difference between Species 3 and Species 4. There is 3 differences between Species 1 and Species 2. This shows these should be branched together with 5 being an outgroup.** **This option is correct. It demonstrates the ability to select the phylogenetic tree that correctly represents evolutionary history and speciation from the data set. The data indicate that species 5 is not closely related to the others and that 3 and 4 are very closely related. This cladogram incorporates those differences as well as the close relationship between 1 and 2. (CollegeBoard)**
	D	Species 3 and Species 4 have one nucleotide difference and should be found on the same branch together. This option is incorrect. The nucleotide differences in species 2 are closer to species 1, and this representation indicates they are linked evolutionarily to all the other species. (CollegeBoard)
10	A	There was no mention of insecticides on the plants
	B	**The prompt states that the flies will typically mate on or near the fruit of their host plants. The apple maggot fly feeds on the hawthorn. The emerging population of flies feeds on domesticated apples which ripen three to four weeks before the hawthorn. Due to this, the two flies will mate at different times. This temporal isolation will inhibit gene flow leading to different species of flies.**
	C	According to the prompt, the flies do not feed on both trees and instead will feed on a specific tree.
	D	Hawthorn flies will reproduce later and will be unable to lay eggs on the earlier ripening apples.
11	A	**Originally when the domestic apple tree was imported in late 1700s/early 1800s, there was no evidence the flies could use them as hosts. Recent analysis shows one population of the flies infests the apple trees. This was rapid because the apple tree was imported recently (200 years ago)**
	B	The flies are native to North American. The trees were imported, but the flies were unable to use them as hosts initially.
	C	The movement of the apples would allow for the flies to be dispersed. Divergence results from an absence of gene flow.
	D	Mutations would allow for changes. Divergence results from an absence of gene flow so only if the mutation inhibited gene flow would it be the cause of the rapid divergence.
12	A	Gamete incompatibility applies to the gametes not fusing for fertilization.
	B	**According to the prompt, apples set fruit earlier in the season and hawthorns set later. The life cycle of the fly populations coordinated with those of the host tree, so this means that the flies on the apple will mate earlier in the season and the flies on the hawthorn will mate later. Since they mate at different times, this is an example of temporal isolation.**
	C	Mechanical isolation applies to an inability to mate due to anatomical differences.
	D	Reduced hybrid viability applies to the hybrids have reduced viability (less healthy).

13	A	Prezygotic isolation occurs prior to the zygote being formed. This inhibits the reproductive event from taking place. There is a hybrid formed which eliminates this answer choice.
	B	Mechanical isolation applies to an inability to mate due to anatomical differences. There is a hybrid formed which eliminates this answer choice.
	C	**The hybrids are healthy but the eggs hatch less often. This is the only postzygotic mechanism in the answer choices.**
	D	Habitat isolation applies to an inability to mate due to different habitats so less likely to come into contact with one another. There is a hybrid formed which eliminates this answer choice.
14	A	Horizontal rock layers will be the same time period, but what time period are you searching? Investigating based on the number of fossils does not represent a geologic timeline. This option is incorrect because the number of fossils is not directly related to any period. (CollegeBoard)
	B	**The Devonian period was 354 million years ago. If you are searching for fossils from that time period, then you can look for fossils BEFORE the Permian period (which occurred before Devonian 248 millions year ago).** **This option is correct because it indicates that a student is able to design a plan for collecting data concerning speciation and extinction throughout the Earth's history. The Devonian period prior to the Permian period did not contain vertebrates, which evolved later. Thus, an area prior to the Permian that contains a few early vertebrates would indicate the Devonian/Permian boundary, which would be an appropriate place for students to collect fossil data. (CollegeBoard)**
	C	Bivalves are found in Cretaceous period and Devonian so just their presence does not represent the fossils are from the Devonian. This option is incorrect because trilobites existed in the Permian, not the Devonian, period. (CollegeBoard)
	D	This answer choice discusses radiometric dating then applying that information to speciation which does not provide information about the fossils in the Devonian. This option is incorrect because the rate of speciation is not related to the location of Devonian fossils. (CollegeBoard)
15	A	This was not supported by Stanley Miller's experiment. He was able to produce organic molecules abiotically. This option is incorrect. The Miller experiment did not model the formation of Earth but rather attempted to model the evolution of biological molecules on Earth. (CollegeBoard)
	B	This was not tested by Stanley Miller. His experiment was determining if organic molecules could be produced abiotically. This option is incorrect. The Miller experiment did not model the conditions on comets or meteorites but rather attempted to model the evolution of biological molecules on Earth. (CollegeBoard)
	C	**Stanley Miller was able to produce biological molecules through an abiotic process. He used inorganic gases and electric sparks, then was about to extract amino acids proving that life today could have formed until early Earth conditions.**

		This option is correct. It demonstrates the ability to evaluate scientific questions about the origin of life on Earth by recognizing that the Miller experiment modeled the presumed early atmospheric conditions and, under laboratory conditions, produced biological molecules, such as amino acids, that were required for early life. (CollegeBoard)
	D	This was not supported by Stanley Miller's experiment as he demonstrated that amino acids could be formed abiotically. This option is incorrect. The molecules formed in the Miller experiment were not proteins. (CollegeBoard)
16	A	If a trait is less favorable, the individual will be less likely to survive so it would leave less offspring.
	B	If an individual is more likely to survive, they will produce and leave more offspring.
	C	**According to Darwin's theory of natural selection, competition for limited resources results in differential survival. Individuals with more favorable phenotypes are more likely to survive and produce more offspring, thus passing traits to subsequent generations. (EVO-1.C.2)**
	D	If a trait is less favorable, the individual will be less likely to survive so it would leave less offspring.
17	A	**Natural selection acts on phenotypic variations in populations. (EVO-1.E.1)**
	B	Genotype is not observed, so natural selection is unable to act on it.
	C	Gene Expression is the process of transcription and translation. Natural selection is selecting for a favorable trait.
	D	Natural selection does not affect reproduction, but if a trait makes an individual more likely to survive, the individual will probably reproduce and leave more offspring.
18	A	Convergent evolution is a similar solution to a similar problem between organisms that are not related.
	B	**Convergent evolution occurs when similar selective pressures result in similar phenotypic adaptations in different populations or species. (EVO-1.G.1)**
	C	Convergent evolution leads to a similar phenotypic adaptation between organisms that are not related.
	D	Convergent evolution is a similar solution to a similar problem between organisms that are not related.
19	A	Crossing over involves exchanging genetic information between nonsister chromatids. This reshuffles existing genetic variation.
	B	Independent assortment involves homologous chromosomes aligning on the metaphase plate during metaphase I. This reshuffles existing genetic variation.
	C	Random fertilization involves a randomness between which sperm and egg fuse in fertilization. This reshuffles existing genetic variation.
	D	**Mutation results in genetic variation, which provides phenotypes on which natural selection acts. (EVO-1.J.1). Mutations add new alleles which increases genetic variation.**
20	A	**During a bottleneck event, there is a drastic decrease of the population size due to a natural disaster. This is a form of genetic drift. This can cause an allele to become fixed as all the individuals have the same allele at all of the loci. This will decrease genetic variation.**
	B	If the allele frequency changes, that represents evolution taking place not a decrease in genetic diversity.
	C	If the genotypic frequency changes, that represents evolution taking place not a decrease in genetic diversity.
	D	If reproductive events are inhibited, this decreases the reshuffling of the alleles but the genetic diversity remains.
21	A	Founder's effect is genetic drift but it will not continue to increase the differences between the two populations.
	B	**During the founder's effect, a small population is separated from the original population. This population has a different allele frequency than the original population. The two populations are**

		separated (absence of gene flow) which increases the differences between the two populations as time progresses.
	C	The new population is a subset of the original population, so there are no harmful alleles added.
	D	If there is a removal of reproductive barriers, the two populations will be able to mate which decreases the differences between the populations.
22	A	Small population size leads to issues with genetic drift. If the population size is decreased, it could have a large effect of the allele frequency.
	B	Nonrandom mating means that sexual selection is at play. If one trait is more favorable to mate with, then the allele frequency will be affected.
	C	**Hardy-Weinberg is a model for describing and predicting allele frequencies in a nonevolving population. Conditions for a population or an allele to be in Hardy-Weinberg equilibrium are—(1) a large population size, (2) absence of migration, (3) no net mutations, (4) random mating, and (5) absence of selection. These conditions are seldom met, but they provide a valuable null hypothesis. (EVO-1.K.1)**
	D	Gene flow (migration) leads to individuals moving in and out of the population which will affect the allele frequency.
23	A	This is q^2 – you are looking for 2pq
	B	You forgot to multiply by 2 for the heterozygous. It is 2pq not pq.
	C	This is p^2 – you are looking for 2pq
	D	**q = 0.4 so p = 0.6 (p + q = 1) → 2pq (heterozygous) = 2 (0.6)(0.4) = 0.48** **Allele frequencies in a population can be calculated from genotype frequencies. (EVO-1.K.2)**
24	A	**Small populations are more susceptible to random environmental impact than large populations. (EVO-1.L.2)**
	B	If there's a tornado that kills 100 individuals, this will affect a population of 500 more than a population of 5000. The 100 is 20% of the first population versus 2% of the second population.
25	A	**DNA sequencing determines the order of nucleotides in a DNA molecule (IST-1.P.1).**
	B	Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—(a) Fossils can be dated by a variety of methods. These include: i. The age of the rocks where a fossil is found (EVO-1.N.1)
	C	Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—(a) Fossils can be dated by a variety of methods. These include: ii. The rate of decay of isotopes including carbon-14 (EVO-1.N.1)
	D	Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—(a) Fossils can be dated by a variety of methods. These include: iii. Geographical data (EVO-1.N.1)
26	A	Analogous structures are due to convergent evolution. There is similar selective pressure which leads to similar trait in different species.
	B	**Molecular, morphological, and genetic evidence from extant and extinct organisms adds to our understanding of evolution—(b) Morphological homologies, including vestigial structures, represent features shared by common ancestry (EVO-1.N.1)**
27	A	Structural evidence indicates common ancestry of all eukaryotes—(a) Membrane-bound organelles (EVO-2.C.1)
	B	Structural evidence indicates common ancestry of all eukaryotes—(b) Linear chromosomes (EVO-2.C.1)
	C	Structural evidence indicates common ancestry of all eukaryotes—(c) Genes that contain introns (EVO-2.C.1)

	D	**All eukaryotes do not have a chloroplast.**
28	A	If the HIV has a mutation in which it's reverse transcriptase does not bind to the HIV drugs, the HIV will be able to make the DNA to incorporate itself into the host DNA.
	B	**Mutations are random changes in the genetic information, but if the mutation allows for reproductive success (able to survive and pass on its genes to another generation)**
	C	HIV is a virus and does not have a cell membrane nor a lysosome.
	D	We have no evidence of the drug being decomposed.
29	A	**The out-group represents the lineage that is least closely related to the remainder of the organisms in the phylogenetic tree or cladogram. (EVO-3.B.1b-iii)**
	B	The most closely related would not be an OUTgroup.
	C	Farther from the common ancestor shows that has evolved the most, versus the outgroup is least closely related.
	D	This shows that the two organisms are closely related if they are located together
30	A	Morphological could be inaccurate due to analogous structures.
	B	**Molecular data typically provide more accurate and reliable evidence than morphological traits in the construction of phylogenetic trees or cladograms (EVO-3.B.1c)**
	C	Biogeographical just means the organisms are in the same area. Just because they are in the same area does not mean they are related.
	D	Temporal refers to time. Temporal isolation is a prezygotic barrier where the organisms mate at different times. I was just filling the blanks.
31	A	Feeble offspring are not healthy.
	B	Feeble offspring are not healthy. Sterile offspring cannot contribute to the gene pool.
	C	**The biological species concept provides a commonly used definition of species for sexually reproducing organisms. It states that species can be defined as a group capable of interbreeding and exchanging genetic information to produce viable, fertile offspring. (EVO-3.D.2)**
	D	Sterile offspring cannot contribute to the gene pool.
32	A	Punctuated is rapid evolution while gradualism occurs slowly.
	B	Allopatric speciation is the creation of a new species due to a separation. Sympatric speciation is the creation of a new species in the same area.
	C	Allopatric speciation is the creation of a new species due to a separation. Sympatric speciation is the creation of a new species in the same area.
	D	**Punctuated equilibrium is when evolution occurs rapidly after a long period of stasis. Gradualism is when evolution occurs slowly over hundreds of thousands or millions of years. (EVO-3.E.1)**
33	A	Behavioral isolation refers to a difference in behaviors. Mating behaviors include: mating song, courtship dance, etc.
	B	**Temporal isolation refers to a difference in time. These organisms will mating at different times of day, month, or year.**
	C	Gametic isolation refers to the gametes being unable to fuse for fertilization.
	D	Ecological isolation is the same as habitat. This refers to the organisms are in two different habitats so there are less chances to meet.
34	A	**Behavioral isolation refers to a difference in behaviors. Mating behaviors include: mating song, courtship dance, etc.**
	B	Temporal isolation refers to a difference in time. These organisms will mating at different times of day, month, or year.
	C	Gametic isolation refers to the gametes being unable to fuse for fertilization.

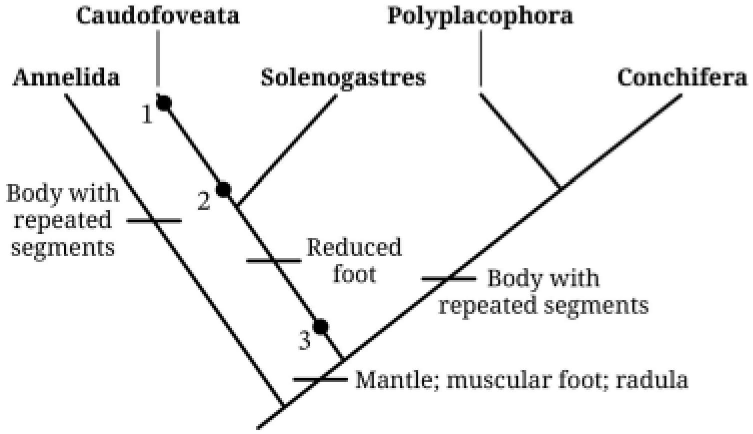
	D	Ecological isolation is the same as habitat. This refers to the organisms are in two different habitats so there are less chances to meet.
35	A	**The amount of diversity in an ecosystem can be determined by the rate of speciation and the rate of extinction (EVO-3.I.1). Speciation is the process of creating new species. This will increase diversity. Extinction is the process of losing species which will decrease diversity.**
	B	Reproduction makes more of the pre-existing organisms and has no effect on the diversity of the ecosystem.
	C	Immigration involves pre-existing organisms moving into the area and has no effect on the diversity of the ecosystem.
	D	Reproduction makes more of the pre-existing organisms and has no effect on the diversity of the ecosystem. Immigration involves pre-existing organisms moving into the area and has no effect on the diversity of the ecosystem.
36	A	There was no life (biotic) so the organic molecules could have been created by abiotic processes.
	B	**There are several models about the origin of life on Earth—(ii) Organic molecules could have been transported to Earth by a meteorite or other celestial event (SYI-3.E.1b)**
	C	Hydrolysis will break bonds. This refers to inorganic molecules. If you break an inorganic molecule, it is still inorganic.
	D	There is no evidence of Earth colliding with another planet.
37	A	DNA is unable to make proteins. The RNA was able to act as an enzyme to replicate (make more RNA) and translate to make proteins.
	B	**The RNA World Hypothesis proposes that RNA could have been the earliest genetic material. (SYI-3.E.2)**
	C	Proteins are unable to make new proteins. If it was the genetic material, it wouldn't be able to replicate or make protein products.
	D	Carbohydrates are sugars. They don't have the variability to be genetic information.

Free Response Practice

2026 CED Q5

Mollusks are a group of invertebrates that include animals such as clams, snails, and octopuses. Although their external phenotypes vary, all mollusks have three shared derived characters: the mantle, the muscular foot, and the radula. A possible evolutionary relationship among four groups of mollusks—Caudofoveata, Solenogastres, Polyplacophora, and Conchifera—is shown in the cladogram in the figure. The cladogram also shows the relationship with Annelida as a group of invertebrates that has a lineage and is an out-group. Horizontal lines indicate the evolution of certain characters.

A Cladogram Representing a Possible Evolutionary Relationship Among Four Groups of Mollusks and One Group of Invertebrates


Caudofoveata
Polyplacophora
Annelida
Solenogastres
Conchifera
1
2
Body with repeated segments
Reduced foot
Body with repeated segments
3
Mantle; muscular foot; radula

(a) **Describe** a difference between Annelida and mollusks that defines Annelida as an outgroup.
(b) **Explain** how two separate lineages represented in the figure have a body with repeated segments.
(c) **Identify** the number from the figure that represents a point at which the genomes of Caudofoveata and Solenogastres were most similar.
(d) **Explain** how genome changes contributed to the formation of the four groups of mollusks and one group of invertebrates.

2025 #4

Twenty million years ago the Caribbean Sea and Pacific Ocean were connected, and water flowed freely between the two bodies of water. Many of the same marine species were found in both areas. Over millions of years, the land referred to as the Isthmus of Panama formed, eventually closing off the connection between the Caribbean Sea and Pacific Ocean and creating two separate bodies of water. The ecology of these two marine habitats was dramatically altered by this land formation. The warmer Caribbean water could no longer flow west, so the Pacific water cooled and became more nutrient-rich, while the Caribbean water became warmer

(a) **Describe** the genetic evidence that evolution is occurring in a population.
(b) **Explain** how the isolation of marine species by the formation of a land barrier can lead to divergent evolution of those species.

The formation of the Isthmus of Panama connected two continents, North America and South America. Many North American land animal species migrated to South America after the formation of the isthmus and occupied similar niches as South American species.

(c) **Predict** the effect the formation of the isthmus had on resource availability for South American species.
(d) **Justify** your prediction in part (c).

2024 #5

Researchers study mechanisms that enable or prevent speciation.

(a) **Describe** a post-zygotic mechanism that prevents gene flow and thus enables speciation.

New genes can evolve from noncoding regions of DNA. It is not until certain regulatory elements are present in the DNA that a noncoding region becomes a new, functional gene that encodes a protein. These regulatory elements include a promoter, a 5′ untranslated region (UTR) followed by a start codon, and a 3′ UTR following a stop codon (Figure 1).

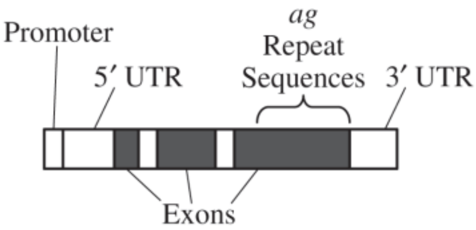
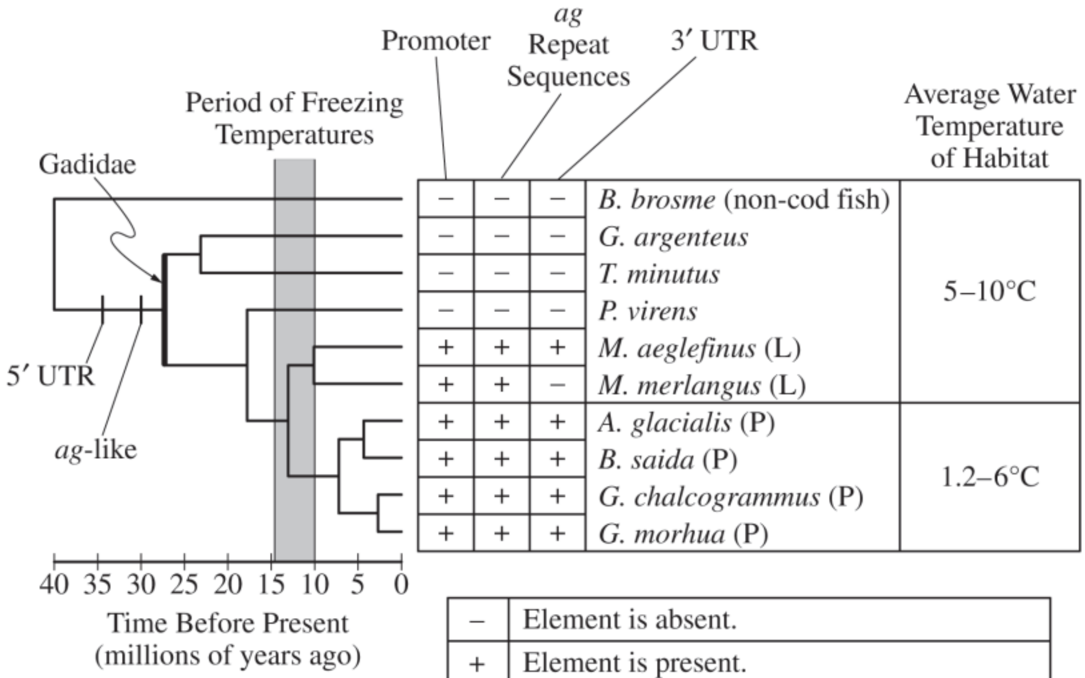


Figure 1. Basic structure of a functional *ag* gene

Researchers studied the evolution of the family of antifreeze-glycoprotein (AG) encoding genes in Gadidae, a family of marine fish known as cods. When present in the fish, these glycoproteins reduce the freezing temperature of the fish. The researchers compared genomic sequences in nine cod species and one non-cod fish species, B. brosme. They recorded the presence or absence of the elements of functional ag genes as well as ag-like sequences that are similar to a functional gene but have undergone mutation and do not contain all the elements required to enable protein production (Figure 2).


Promoter
ag Repeat Sequences
3′ UTR
Period of Freezing Temperatures
Gadidae
Average Water Temperature of Habitat
– – – B. brosme (non-cod fish)
– – – G. argenteus
– – – T. minutus
– – – P. virens
+ + + M. aeglefinus (L)
+ + – M. merlangus (L)
+ + + A. glacialis (P)
+ + + B. saida (P)
+ + + G. chalcogrammus (P)
+ + + G. morhua (P)
5–10°C
1.2–6°C
5′ UTR
ag-like
40 35 30 25 20 15 10 5 0
Time Before Present (millions of years ago)

–	Element is absent.
+	Element is present.
L	Functional *ag* genes are lost.
P	Functional *ag*-encoded proteins are present.

Figure 2. Phylogenetic tree showing the evolution of *ag* genes

(b) Based on the data in Figure 2, **explain** how changes to the genome enabled cods to survive and reproduce after a period of freezing temperatures between 10 and 15 million years ago.

(c) Using the template in the space provided for your response, place an "X" on the phylogenetic tree to **represent** the origin of the functional ag gene.

(d) Based on Figure 2, **explain** how genetic differences among the species in the Gadidae family determine the habitats in which they can survive.

2023 #5

Ruminants are hoofed animals, including cattle and sheep, that have a unique four-chambered stomach specialized to digest tough, fiber-filled grasses. Researchers studying ruminants are investigating the morphological and molecular characteristics of different ruminant families in order to determine the evolutionary relationships among the families. Cladograms of several ruminant families were constructed based on morphological data (Figure 1A) and molecular data (Figure 1B). Table 1 shows a sample of the morphological characteristics present in each family used to construct the cladogram in Figure 1A.

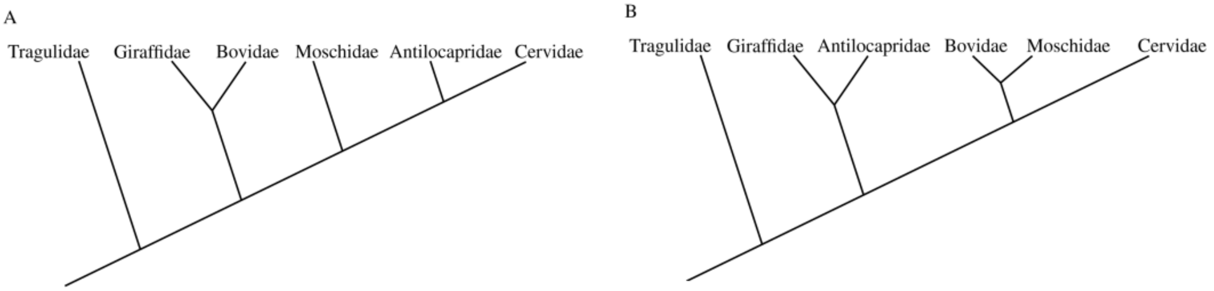

A
Tragulidae
Giraffidae
Bovidae
Moschidae
Antilocapridae
Cervidae
B
Tragulidae
Giraffidae
Antilocapridae
Bovidae
Moschidae
Cervidae

Figure 1. Cladogram of six ruminant families based on (A) morphological data and (B) molecular data

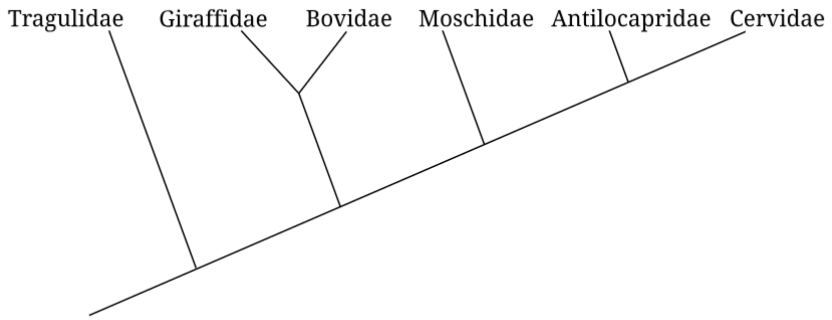
TABLE 1. MORPHOLOGICAL CHARACTERISTICS FOUND IN EACH RUMINANT FAMILY

Characteristic Number	Morphological Characteristic	Tragulidae	Giraffidae	Bovidae	Moschidae	Antilocapridae	Cervidae
1	Extra tooth material			X		X	
2	Third stomach		X	X	X	X	X
3	Double opening for tear ducts					X	X

(a) **Describe** how a scientist would use a comparison of the DNA sequences of different organisms to suggest the most likely evolutionary relationship among the organisms.

(b) Based on Figure 1, **explain** why Bovidae is likely to be more closely related to Moschidae than it is to Giraffidae.

(c) Using the template in the space provided for your response, **represent** the point(s) at which characteristic 1, listed in Table 1, evolved by marking "X" on the line(s) of the cladogram in the correct location(s).


Tragulidae
Giraffidae
Bovidae
Moschidae
Antilocapridae
Cervidae

(d) Based on Figure 1A, **explain** why a characteristic found only in the Cervidae and Bovidae families is more likely evidence of convergent evolution than it is of common ancestry.

2022 #4

Existing isolated brook trout populations in Newfoundland, Canada, were once part of a larger population that was fragmented at the end of the most recent glaciation period about 10,000 to 12,000 years ago. Researchers investigated 14 naturally separated stream populations of brook trout. They found that the populations are all genetically distinct and show differences in morphology.

(a) **Describe** the prezygotic barrier that results in these genetically distinct populations.

(b) Brook trout with longer fins are able to swim faster than brook trout with shorter fins. In one of the Newfoundland streams, the main prey of the brook trout evolved to move faster. For brook trout living in this stream, **explain** the difference in fitness between longer-finned individuals and shorter-finned individuals.

(c) If two morphologically and behaviorally distinct populations of brook trout remain isolated for many generations, **predict** the likely impact on both populations.

(d) Researchers claim that there are more genetic differences between any two current brook trout populations than there are between any single current population and the ancestral brook trout population from which all the trout are descended. Provide reasoning to **justify** their claim.

2021 #4

In 1981 a single immature male *Geospiza conirostris* finch flew more than 100 kilometers from the Galapagos island of Espanola to the Galapagos island of Daphne Major, where no *G. conirostris* finches were living. The immigrant finch bred with a female *G. fortis*, a species of finch common on Daphne Major. The F1 finches and later generations interbred only within their lineage. By 2012 scientists counted 23 individuals, including eight breeding pairs, within this hybrid lineage on Daphne Major. The hybrid lineage became known as Big Bird.

Bird with different beak shapes and sizes eat different types of food. The dimensions of the Big Bird beaks relative to the beaks of the major competitor finch species on Daphne Major are shown in Figure 1.

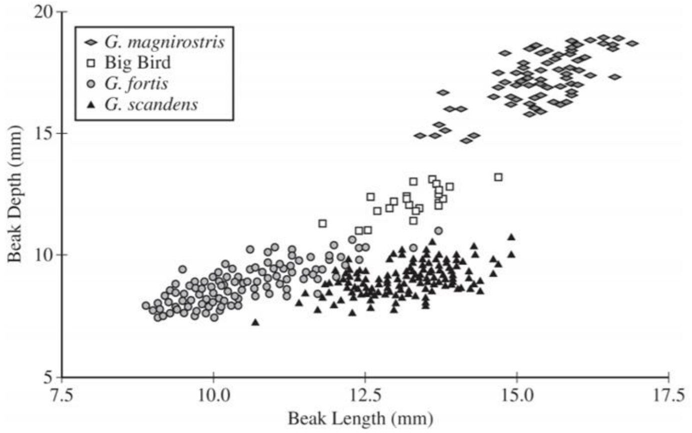


Figure 1. The dimensions of the beaks of the Big Bird lineage and of its major competitor species in 2012 on Daphne Major. Each symbol represents the beak dimensions of a single bird.

(a) The Big Bird lineage became reproductively isolated from *G. fortis*. **Describe** one prezygotic mechanism that likely contributed to the reproductive isolation of the Big Bird lineage from *G. fortis*.

(b) Based on the data in Figure 1, **explain** why the Big Bird population has been able to survive and reproduce on Daphne Major.

(c) A virus infects and kills all *G. magnirostris* on Daphne Major but does not affect the other finch species. Assuming food type and availability stay the same, **predict** the most likely change in the beak phenotype of the Big Bird population after six more generations.

(d) Provide reasoning to **justify** your prediction in part (c).

2019 #1

This question is in Unit 8.

2019 #2

This question is in Unit 8.

2019 #5

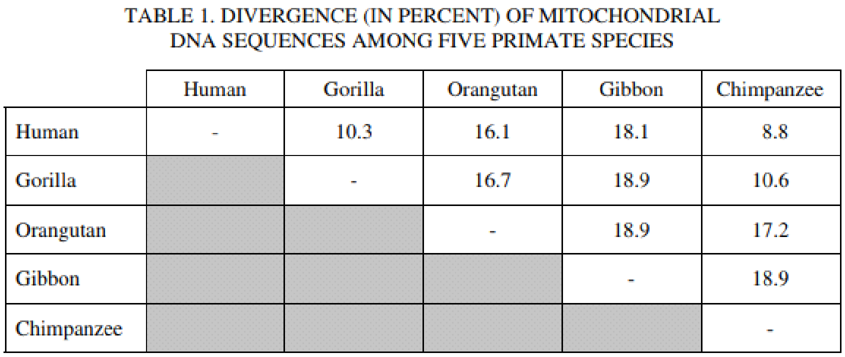


TABLE 1. DIVERGENCE (IN PERCENT) OF MITOCHONDRIAL DNA SEQUENCES AMONG FIVE PRIMATE SPECIES

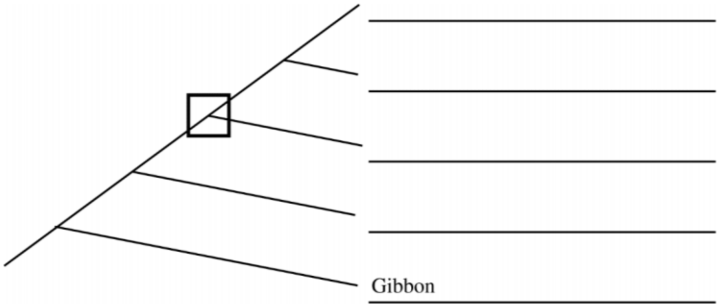
	Human	Gorilla	Orangutan	Gibbon	Chimpanzee
Human	-	10.3	16.1	18.1	8.8
Gorilla		-	16.7	18.9	10.6
Orangutan			-	18.9	17.2
Gibbon				-	18.9
Chimpanzee					-

A researcher studying the evolutionary relationship among five primate species obtained data from a sequence of mitochondrial DNA (mtDNA) from a representative individual of each species. The researcher then calculated the percent divergence in the sequences between each pair of primate species (Table 1).

(a) Based on fossil data, the researcher estimates that humans and their most closely related species in the data set diverged approximately seven million years ago. Using these data, **calculate** the rate of mtDNA percent divergence per million years between humans and their most closely related species in the data set. Round your answer to two decimal places.

(b) Using the data in the table, **construct** a cladogram on the template provided. **Provide reasoning** for the placement of gibbons as the outgroup on the cladogram.

(c) On the cladogram, **draw** a circle around all of the species that are descended from the species indicated by the node within the square.



2018 #1

Polar bears are highly adapted for life in cold climates around the North Pole. Brown bears, black bears, and pandas are found in warmer environments. Researchers collected complete mitochondrial DNA sequences from several populations of bears and constructed a phylogenetic tree to represent their evolutionary relatedness (Figure 1).

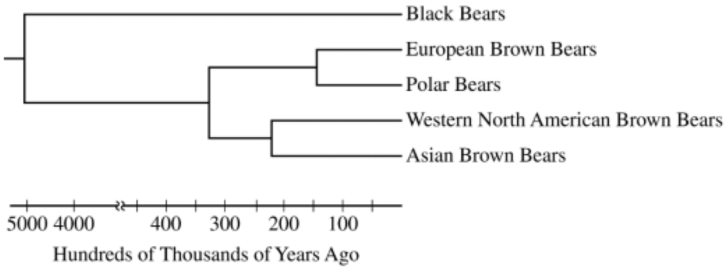


Figure 1. Phylogenetic tree representing the evolutionary relatedness among bear populations based on mitochondrial DNA sequence comparisons

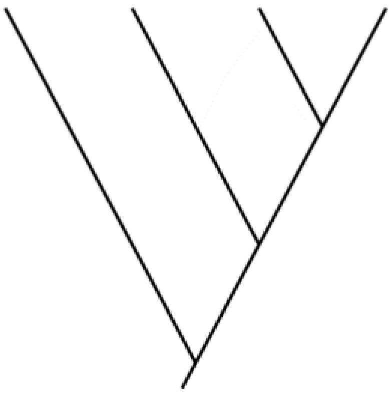
A researcher studying adaptations in bears sequenced the nuclear gene encoding a lysosomal trafficking protein (LYST) in polar bears, brown bears, and panda bears. There are seven inferred amino acid substitutions that are found only in polar bears. Mutations that cause similar substitutions in the human LYST protein are associated with Chediak-Higashi syndrome, an autosomal recessive condition in which pigment is absent from the hair and eyes. The researcher used the inferred amino acid sequences to build the distance matrix shown in Table 1.

TABLE 1. AMINO ACID DIFFERENCES IN THE LYST PROTEIN AMONG BEAR SPECIES

	Panda	Black	Brown	Polar
Panda	–			
Black	33	–		
Brown	34	1	–	
Polar	40	7	8	–

(a) Use the phylogenetic tree in Figure 1 to **estimate** the age in hundreds of thousands of years of the most recent common ancestor of all brown bears. **Identify** the population of brown bears to which polar bears are most closely related based on the mitochondrial DNA sequence comparison. **Identify** two populations whose positions could be switched without affecting the relationships illustrated in the cladogram.

(b) **Construct** a cladogram on the template to represent a model of the evolutionary relatedness among the bear species based on the differences in LYST protein sequences (Table 1). **Circle** the position on the cladogram that represents the out-group.



(c) A student claims that mitochondrial DNA sequence comparisons provide a more accurate phylogeny of bear species than do LYST protein sequence comparisons. **Provide ONE piece of reasoning** to support the student's claim.

(d) A researcher genetically engineers a mouse strain by deleting the mouse *lyst* gene and replacing it with the polar bear *lyst* gene. **Predict** the most likely difference in phenotype of the transgenic mouse strain compared to the wild-type mouse strain. **Justify** your prediction.

(e) **Describe** how the mutation in the *lyst* gene became common in the polar bear population. If the *lyst* gene were the only determinant of the fur color, **predict** the percent of white offspring produced by a mating between a polar bear and a brown bear.

2016 #1

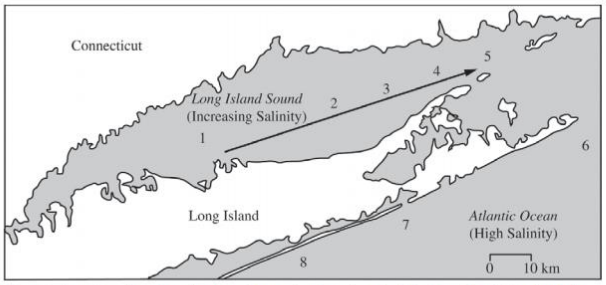
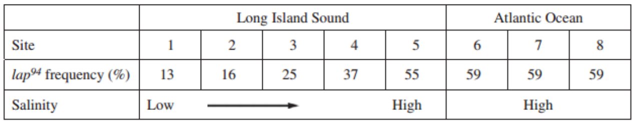


Figure 1. Sampling sites of marine mussels at various locations (1–8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*^{94} ALLELE



	Long Island Sound					Atlantic Ocean		
Site	1	2	3	4	5	6	7	8
lap^{94} frequency (%)	13	16	25	37	55	59	59	59
Salinity	Low → High					High		

Leucine aminopeptidase (LAPs) are found in all living organisms and have been associated with the response of the marine mussel, *Mytilus edulis*, to changes in salinity. LAPs are enzymes that remove N-terminal amino acids from proteins and release the free amino acids into the cytosol. To investigate the evolution of LAPs in wild populations of *M. edulis*, researchers sampled adult mussels from several different locations along a part of the northeast coast of the United States, as shown in Figure 1. The researchers then determined the percent of individuals possessing a particular *lap* allele, *lap*^{94}, in mussels from each sample site (table 1).

(a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the *lap*^{94} allele in the study population.

(b) Based on the data, **describe** the most likely effect of salinity on the frequency of the *lap*^{94} allele in the marine mussel population in Long Island Sound. **Predict** the likely *lap*^{94} allele frequency at a sampling site between site 1 and site 2 in Long Island Sound.

(c) **Describe** the most likely effect of LAP^{94} activity on the osmolarity of the cytosol. **Describe** the function of LAP^{94} in maintaining water balance in mussels living in the Atlantic Ocean.

(d) Marine mussel larvae are evenly dispersed throughout the study area by water movement. As larvae mature, they attach to the rocks in the water. **Explain** the differences in *lap*^{94} allele frequency among adult mussel populations at the sample sites despite the dispersal of larvae throughout the entire study area. **Predict** the likely effect of distribution of mussels in Long Island Sound if the *lap*^{94} allele was found in all the mussels in the population. **Justify** your prediction.

2016 #3

This question is in Unit 8.

2015 #1

This question is in Unit 8.

2015 #2

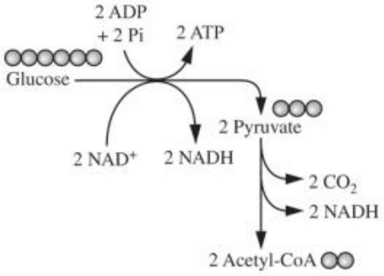


Figure 1. Glycolysis and pyruvate oxidation

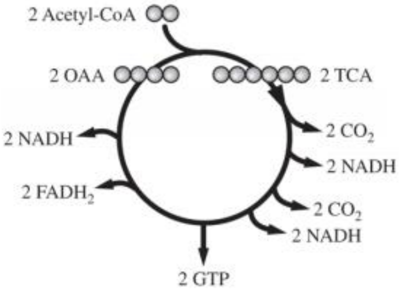


Figure 2. Krebs cycle

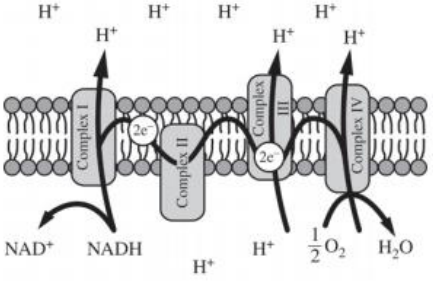


Figure 3. Electron transport chain

Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

(a) Using the information above, **describe** ONE contribution of each of the following in ATP synthesis.
- Catabolism of glucose in glycolysis and pyruvate oxidation
- Oxidation of intermediates in the Krebs cycle
- Formation of a proton gradient by the electron transport chain

(b) Use each of the following observations to **justify** the claim that glycolysis first occurred in a common ancestor of all living organisms.
- Nearly all existing organisms perform glycolysis.
- Glycolysis occurs under anaerobic conditions.
- Glycolysis occurs only in the cytosol.

(c) A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

(d) The enzymes of the Krebs cycle function in the cytosol of bacteria, but among eukaryotes the enzymes function mostly in the mitochondria. **Pose** a scientific question that connects the subcellular location of the enzymes in the Krebs cycle to the evolution of eukaryotes.

2015 #3

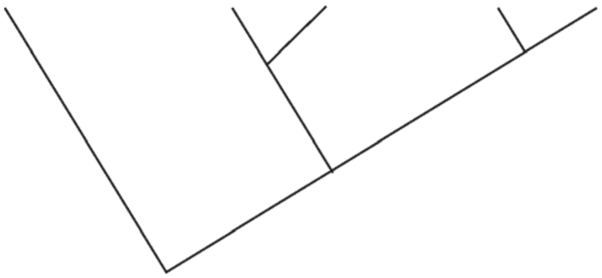
The amino acid sequence of cytochrome c was determined for five different species of vertebrates. The table below shows the number of differences in the sequences between each pair of species.

THE NUMBER OF AMINO ACID DIFFERENCES IN CYTOCHROME c AMONG FIVE SPECIES

	E. ferus	*D. polylepis*	*G. gallus*	*A. forsteri*	*E. africanus*
E. ferus	0	21	11	13	1
D. polylepis		0	18	17	20
G. gallus			0	3	10
A. forsteri				0	12
E. africanus					0

(a) Using the data in the table, **create** a phylogenetic tree on the template provided to reflect the evolutionary relationships of the organisms. **Provide reasoning** for the placement on the tree of the species that is least related to the others.

(b) **Identify** whether morphological data or amino acid sequence data are more likely to accurately represent the true evolutionary relationships among the species, and **provide reasoning** for your answer.



2014 #2

Mammalian milk contains antibodies that are produced by the mother's immune system and passed to offspring during feeding. Mammalian milk also contains a sugar (lactose) and may contain proteins (protein A, protein B, and casein), as indicated in the table.

MILK COMPONENTS IN DIFFERENT MAMMALS

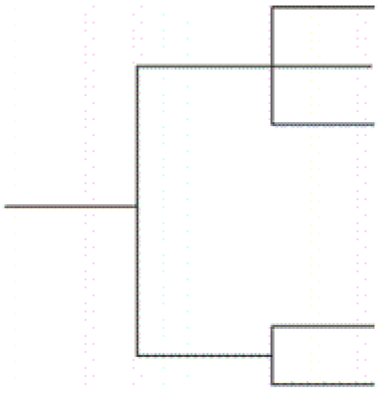
Character	Cat	Cow	Horse	Human	Pig
Lactose	+	+	+	+	+
Protein A	+	+	+	+	+
Protein B	?	+	+	?	+
Casein	?	+	+	?	+
? indicates the absence of the character + indicates the presence of the character					

(a) Using the data in the table, **construct** a cladogram on the template provided to indicate the most likely evolutionary relationships among the different mammals. **Indicate** on the cladogram where each of the characters most likely arose in the evolutionary process, and **justify** the placement of the characters on the cladogram.

Note: part b & c are out of scope

(b) **Describe** FOUR steps in the activation of the mother's specific immune response following exposure to a bacterial pathogen. **Predict** how the mother's immune response would differ upon a second exposure to the same bacterial pathogen a year later.

(c) **Predict** the most likely consequence for a nursing infant who is exposed to an intestinal bacterial pathogen (e.g. *Salmonella*) to which the mother was expose three months earlier. **Justify** your prediction.



2014 #4

This question is in Unit 8.

2014 #5

This question is in Unit 8.

2014 #8

A research team has genetically engineered a strain of fruit flies to eliminate errors during DNA replication. The team claims that this will eliminate genetic variation in the engineered flies. A second research team claims that eliminating errors during DNA replication will not entirely eliminate genetic variation in the engineered flies.

(a) **Provide** ONE piece of evidence that would indicate new genetic variation has occurred in the engineered flies.

(b) **Describe** ONE mechanism that could lead to genetic variation in the engineered strain of flies.

(c) **Describe** how genetic variation in a population contributes to the process of evolution in the population.

2013 #3

Fossils of lobe-finned fishes, which are ancestors of amphibians, are found in rocks that are at least 380 million years old. Fossils of the oldest amphibian-like vertebrate animals with true legs and lungs are found in rocks that are approximately 363 million years old.

Three samples of rocks are available that might contain fossils of a transitional species between lobe-finned fishes and amphibians: one rock sample that is 350 million years old, one that is 370 million years old, and one that is 390 million years old.

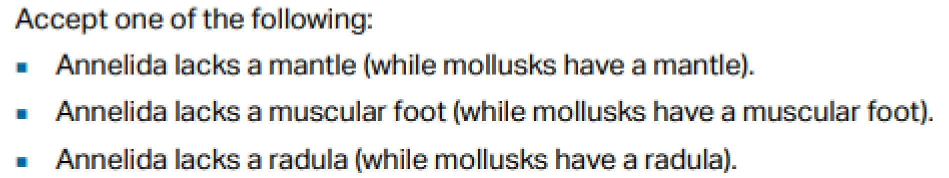
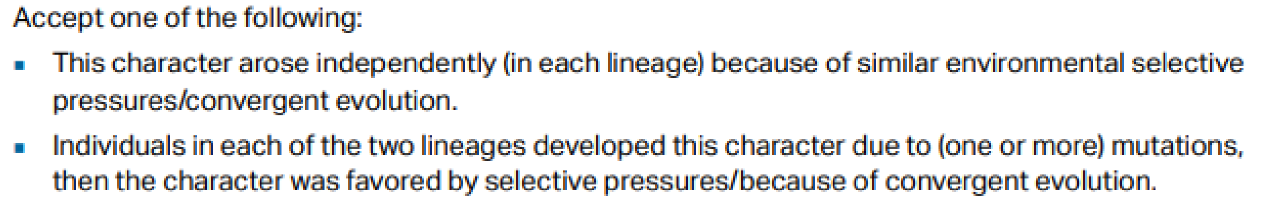
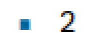
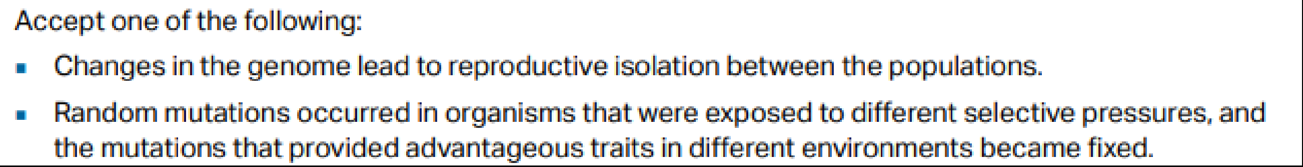
(a) **Select** the most appropriate sample of rocks in which to search for a transitional species between lobe-finned fishes and amphibians. **Justify** your selection.

(b) **Describe** TWO pieces of evidence provided by fossils of a transitional species that would support a hypothesis that amphibians evolved from lobe-finned fishes.

AP Biology Exam Review

Free Response Scoring Guidelines

<table>
<tr><th colspan="2">2026 CED Q5</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>7.4: Population Genetics
• 7.4.A: Explain how random occurrences affect the genetic makeup of a population.
7.9: Phylogeny
• 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship.
• 7.9.B: Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.
7.10: Speciation
• 7.10.A: 7.10.A: Describe the conditions under which new species may arise.
• 7.10.B: Describe the rate of evolution and speciation under different ecological conditions.</td><td>1.A: Describe biological concepts and processes.
2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts.
2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories.
2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.</td></tr>
</table>

<table>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>Accept one of the following:
▪ Annelida lacks a mantle (while mollusks have a mantle).
▪ Annelida lacks a muscular foot (while mollusks have a muscular foot).
▪ Annelida lacks a radula (while mollusks have a radula).</td></tr>
<tr><td>(b)</td><td>Accept one of the following:
▪ This character arose independently (in each lineage) because of similar environmental selective pressures/convergent evolution.
▪ Individuals in each of the two lineages developed this character due to (one or more) mutations, then the character was favored by selective pressures/because of convergent evolution.</td></tr>
<tr><td>(c)</td><td>▪ 2</td></tr>
<tr><td>(d)</td><td>Accept one of the following:
▪ Changes in the genome lead to reproductive isolation between the populations.
▪ Random mutations occurred in organisms that were exposed to different selective pressures, and the mutations that provided advantageous traits in different environments became fixed.</td></tr>
</table>

<table>
<tr><th colspan="2">2025 #4</th></tr>
<tr><th>Course Content</th><th>Practice and Skill</th></tr>
<tr><td>7.4: Population Genetics
• 7.4.B: Describe the role of random processes in the evolution of specific populations.
7.10: Speciation
• 7.10.A: 7.10.A: Describe the conditions under which new species may arise.</td><td>1.A: Describe biological concepts and processes.
2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts.
2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories.</td></tr>
</table>

- 7.10.B: Describe the rate of evolution and speciation under different ecological conditions. 8.5: Community Ecology - 8.5.B: Explain how interactions within and among populations influence community structure.	2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Part	Scoring Guidelines
(a)	Examples of acceptable responses may include the following: • There are changes in allele/gene frequencies. • There are heritable changes in phenotypes.
(b)	Examples of acceptable responses may include the following: • Selective pressures could result in different allele/gene frequencies. • (The land barrier) results in reproductive isolation/lack of gene flow/allopatric speciation. • Different environmental conditions/pressures select for different alleles/genotypes/phenotypes.
(c)	• (Resource availability) would have decreased.
(d)	• More species would now be competing for the same resources, (resulting in fewer resources for each individual).

Scoring Statistics

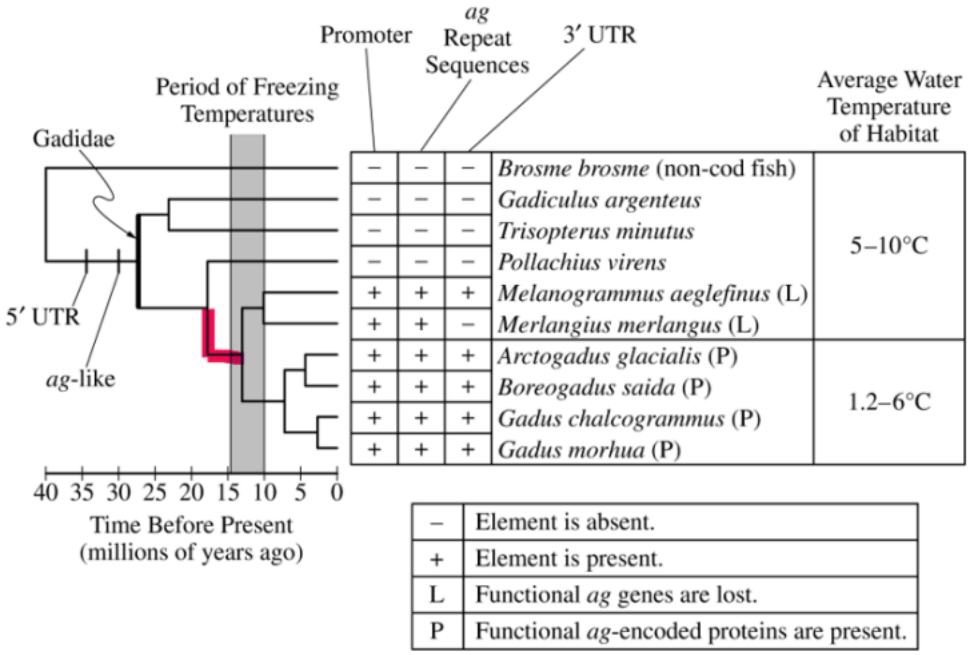
	Max Points:	**Mean Score:**
Part A	1.0	0.12
Part B	1.0	0.27
Part C	1.0	0.71
Part D	1.0	0.61

Overall Mean Score: 1.72

2024 #5

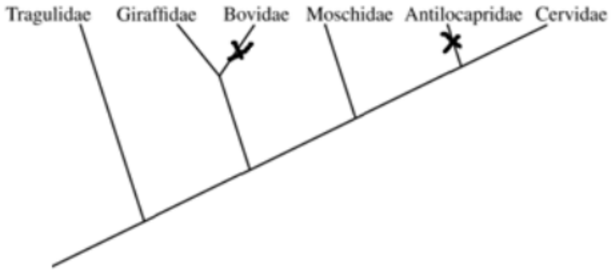
Course Content	Practice and Skill
7.3: Artificial Selection - 7.3.A Explain how humans can affect diversity within a population. 7.8: Continuing Evolution - 7.8.A: Explain how evolution is an ongoing process in all living organisms. 7.9: Phylogeny - 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship. 7.10: Speciation - 7.10.C: Explain the processes and mechanisms that drive speciation.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Part	Scoring Guidelines

(a)	- The offspring do not survive (long enough to reproduce)/cannot (successfully) reproduce.
(b)	- (Over time) the addition of the promoter/*ag* repeat sequences/ 3′ UTR/regulatory elements led to emergence of new genes/*ag* genes/functional gene products (that prevent freezing).
(c)	- An X is placed anywhere along the colored L-shaped line in the figure.  Promoter *ag* Repeat Sequences 3′ UTR Period of Freezing Temperatures Gadidae Average Water Temperature of Habitat *Brosme brosme* (non-cod fish) *Gadiculus argenteus* *Trisopterus minutus* *Pollachius virens* *Melanogrammus aeglefinus* (L) *Merlangius merlangus* (L) *Arctogadus glacialis* (P) *Boreogadus saida* (P) *Gadus chalcogrammus* (P) *Gadus morhua* (P) 5–10°C 1.2–6°C 5′ UTR *ag*-like 40 35 30 25 20 15 10 5 0 Time Before Present (millions of years ago) – Element is absent. + Element is present. L Functional *ag* genes are lost. P Functional *ag*-encoded proteins are present.
(d)	- Species with the functional *ag* gene/antifreeze glycoprotein are able to live in colder water/lower temperatures (than are species without the functional gene).

Scoring Statistics	
Mean: 0.80	Standard Deviation: 0.93

2023 #5	
Course Content	**Practice and Skill**
7.6: Evidence of Evolution - 7.6.B: Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time. 7.9: Phylogeny - 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship. 7.10: Speciation - 7.10.B: Describe the rate of evolution and speciation under different ecological conditions.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.
Part	**Scoring Guidelines**

(a)	**Describe** how a scientist would use a comparison of the DNA sequences of different organisms to suggest the most likely evolutionary relationship among the organisms. • The (DNA) sequences of organisms that are more closely related are more similar (than those of organisms that are less closely related).
(b)	Based on Figure 1, **explain** why Bovidae is likely to be more closely related to Moschidae than it is to Giraffidae. Accept one of the following: • (The molecular data/Figure 1B support(s) this relationship, and) molecular data are more reliable (than are morphological data). • (The molecular data/Figure 1B support(s) this relationship.) Morphological similarities may not reliably indicate evolutionary relatedness.
(c)	Using the template in the space provided for your response, **represent** the point(s) at which characteristic 1, listed in Table 1, evolved by marking “X” on the line(s) of the cladogram in the correct location(s). Sample Response:  Tragulidae Giraffidae Bovidae Moschidae Antilocapridae Cervidae • Response must show an X placed on the line leading to Bovidae and an X placed on the line leading to Antilocapridae.
(d)	Based on Figure 1A, **explain** why a characteristic found only in the Cervidae and Bovidae families is more likely evidence of convergent evolution than it is of common ancestry. Accept one of the following: • There are other families that have the same common ancestor as the Bovidae and Cervidae families but do not have the characteristic. • It is more likely that the characteristic arose independently in Cervidae and Bovidae than it arose in their common ancestor and was lost in Giraffidae, Moschidae, and Antilocapridae.

Scoring Statistics	
Mean: 1.19	Standard Deviation: 1.15

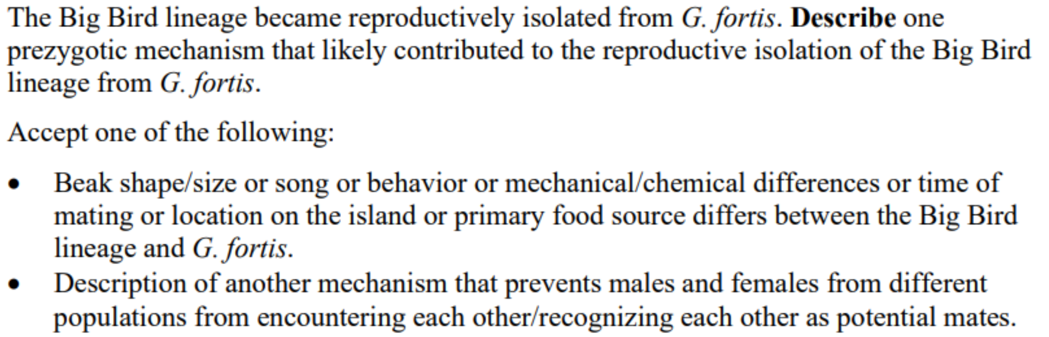
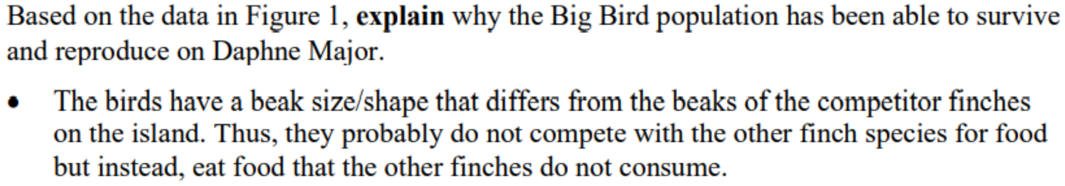
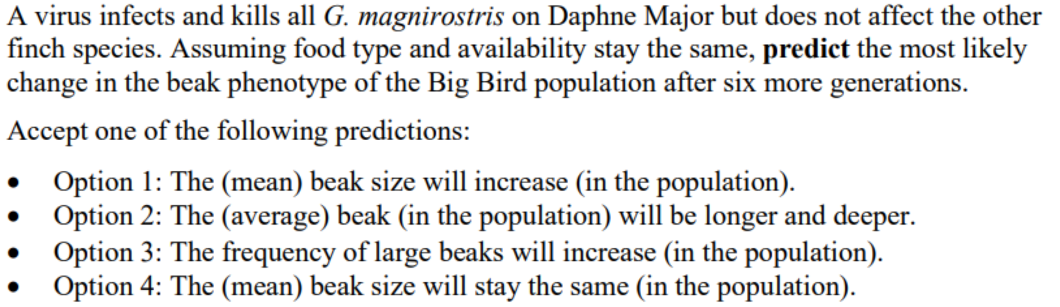
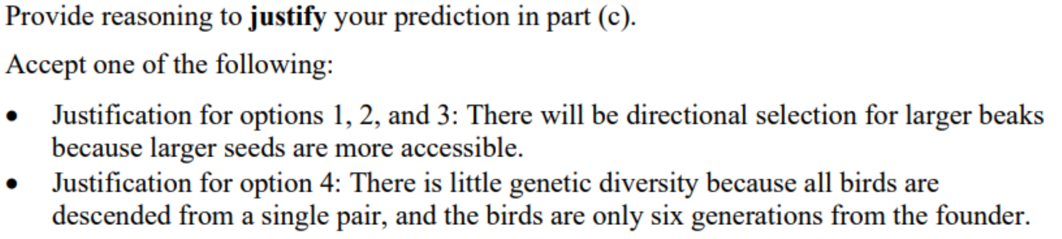
2022 #4

Course Content	Practice and Skill
7.2: Natural Selection • 7.2.A: Describe the importance of phenotypic variation in a population. 7.10: Speciation • 7.10.A: Describe the conditions under which new species may arise. • 7.10.B: Describe the rate of evolution and speciation under different ecological conditions. • 7.10.C: Explain the processes and mechanisms that drive speciation.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

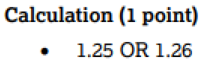
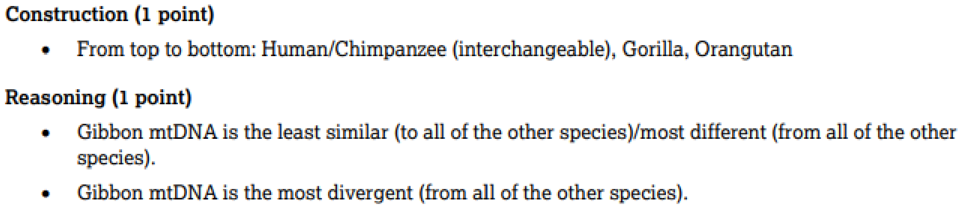
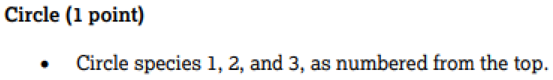
Part	Scoring Guidelines
(a)	**Describe** the prezygotic barrier that results in these genetically distinct populations. • Geographic isolation prevents gene flow between the populations.
(b)	Brook trout with longer fins are able to swim faster than brook trout with shorter fins. In one of the Newfoundland streams, the main prey of the brook trout evolved to move faster. For brook trout living in this stream, **explain** why there is a difference in fitness between longer-finned individuals and shorter-finned individuals. • Individuals with longer fins are more likely to capture prey and reproduce.
(c)	If two morphologically and behaviorally distinct populations of brook trout remain isolated for many generations, **predict** the likely impact on both populations. Accept one of the following: • The two populations will become separate species. • The two populations will continue diverging (behaviorally/morphologically/ genetically).
(d)	Researchers claim that there are more genetic differences between any two current brook trout populations than there are between any single current population and the ancestral brook trout population from which all the trout are descended. Provide reasoning to **justify** their claim. Accept one of the following: • Each single population has accumulated mutations/experienced genetic drift (distinguishing it from the ancestral population). The mutations each population accumulated are likely to differ (as a result of different selective pressures). • Allele production (as a result of random mutation) and genetic drift/selection by local environmental conditions has resulted in a collection of alleles unique to each population.

Scoring Statistics	
Mean: 1.08	Standard Deviation: 0.97

2021 #4	
Course Content	Practice and Skill
7.1: Introduction to Natural Selection • 7.1.A: Describe the causes of natural selection. 7.10: Speciation • 7.10.C: Explain the processes and mechanisms that drive speciation. 8.7: Disruptions in Ecosystems • 8.7.B: Explain how invasive species affect ecosystem dynamics.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	 The Big Bird lineage became reproductively isolated from *G. fortis*. **Describe** one prezygotic mechanism that likely contributed to the reproductive isolation of the Big Bird lineage from *G. fortis*. Accept one of the following: • Beak shape/size or song or behavior or mechanical/chemical differences or time of mating or location on the island or primary food source differs between the Big Bird lineage and *G. fortis*. • Description of another mechanism that prevents males and females from different populations from encountering each other/recognizing each other as potential mates.
(b)	 Based on the data in Figure 1, **explain** why the Big Bird population has been able to survive and reproduce on Daphne Major. • The birds have a beak size/shape that differs from the beaks of the competitor finches on the island. Thus, they probably do not compete with the other finch species for food but instead, eat food that the other finches do not consume.
(c)	 A virus infects and kills all *G. magnirostris* on Daphne Major but does not affect the other finch species. Assuming food type and availability stay the same, **predict** the most likely change in the beak phenotype of the Big Bird population after six more generations. Accept one of the following predictions: • Option 1: The (mean) beak size will increase (in the population). • Option 2: The (average) beak (in the population) will be longer and deeper. • Option 3: The frequency of large beaks will increase (in the population). • Option 4: The (mean) beak size will stay the same (in the population).
(d)	 Provide reasoning to **justify** your prediction in part (c). Accept one of the following: • Justification for options 1, 2, and 3: There will be directional selection for larger beaks because larger seeds are more accessible. • Justification for option 4: There is little genetic diversity because all birds are descended from a single pair, and the birds are only six generations from the founder.

Scoring Statistics	
Mean: 1.60	Standard Deviation: 1.19

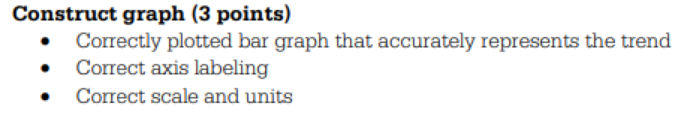
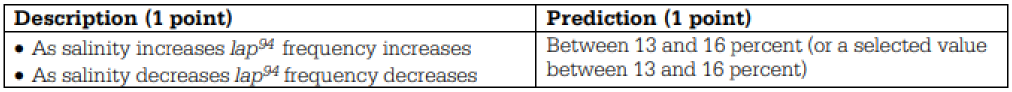
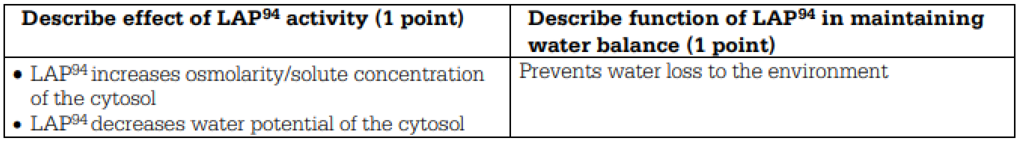
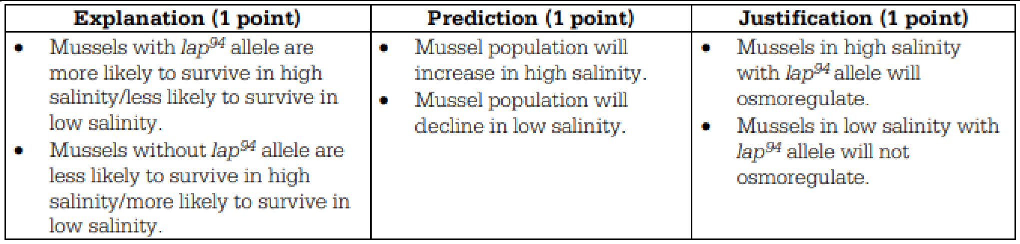
<table>
<tr><th colspan="3">2019 #5</th></tr>
<tr><th colspan="2">Course Content</th><th>Practice and Skill</th></tr>
<tr><td colspan="2">7.6: Evidence of Evolution
• 7.6.B: Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.
7.9: Phylogeny
• 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship.</td><td>2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories.
2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.
5.A: Perform mathematical calculations</td></tr>
<tr><th>Part</th><th colspan="2">Scoring Guidelines</th></tr>
<tr><td>(a)</td><td colspan="2">
Calculation (1 point)
• 1.25 OR 1.26</td></tr>
<tr><td>(b)</td><td colspan="2">
Construction (1 point)
• From top to bottom: Human/Chimpanzee (interchangeable), Gorilla, Orangutan
Reasoning (1 point)
• Gibbon mtDNA is the least similar (to all of the other species)/most different (from all of the other species).
• Gibbon mtDNA is the most divergent (from all of the other species).</td></tr>
<tr><td>(c)</td><td colspan="2">
Circle (1 point)
• Circle species 1, 2, and 3, as numbered from the top.</td></tr>
<tr><th colspan="3">Scoring Statistics</th></tr>
<tr><td colspan="2">Mean: 1.88</td><td>Standard Deviation: 1.38</td></tr>
</table>

<table>
<tr><th colspan="3">2018 #1</th></tr>
<tr><th colspan="2">Course Content</th><th>Practice and Skill</th></tr>
<tr><td colspan="2">6.7: Mutations
• 6.7.A: Describe the various types of mutation.
• 6.7.B: Explain how changes in genotype may result in changes in phenotype.
7.9: Phylogeny
• 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship.
• 7.9.B: Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.</td><td>1.A: Describe biological concepts and processes.
2.A: Describe characteristics of visual representations of biological concepts and processes.
2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.
4.B: Describe data from a table or graph
6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.
6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.</td></tr>
<tr><th>Part</th><th colspan="2">Scoring Guidelines</th></tr>
</table>

(a)	**Estimate (1 point)** • First two digits of the answer must be between 30 and 35. **Identification (1 point)** • European **Identification (1 point)** • European/Polar OR Asian/Western (North American)
(b)	**Construction (1 point)** • Correctly illustrated evolutionary relationship among the four species **Circling (1 point)** • Correctly circled out-group based on orientation of cladogram
(c)	**Reasoning (1 point)** • Genes show more variability (in nucleotide sequence) than proteins do (in amino acid sequences). • mtDNA genome contains multiple genes vs. one *lyst* gene. • The phenotype associated with the *lyst* gene is under strong selection.
(d)	**Prediction (1 point)** • Mouse fur and/or eyes will not have pigment/will have reduced pigment. • Mouse (fur) will be white/lighter. **Justification (1 point)** • Polar bear *lyst* gene/LYST protein is associated with a lack of pigment/white hair. • Mutated human *lyst* gene/ LYST protein is associated with a lack of pigment in hair and eyes.
(e)	**Description (1 point)** • Natural selection for the white fur phenotype **Prediction (1 point)** • 0%

Scoring Statistics	
Mean: 4.73	Standard Deviation: 2.42

2016 #1	
Course Content	Practice and Skill
2.7: Tonicity and Osmoregulation • 2.7.A: Explain how concentration gradients affect the movement of molecules across membranes. 7.11: Variations in Populations • 7.11.A: Explain how the genetic diversity of a species or population affects its ability to withstand environmental pressures.	2.A: Describe characteristics of visual representations of biological concepts and processes. 4.A: Construct a graph to represent the data 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.D: Explain the relationship between experimental results and larger biological concepts, processes, or theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.
Part	Scoring Guidelines

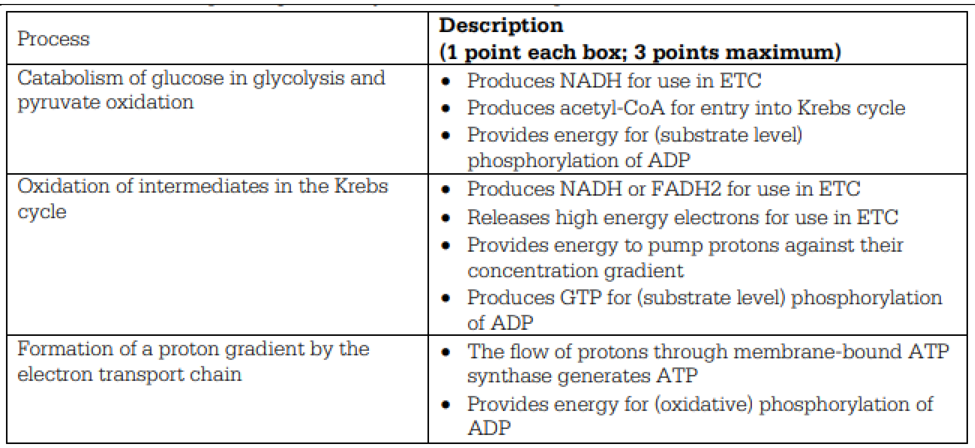
(a)	 **Construct graph (3 points)** • Correctly plotted bar graph that accurately represents the trend • Correct axis labeling • Correct scale and units
(b)	 **Description (1 point)** • As salinity increases *lap*^{94} frequency increases • As salinity decreases *lap*^{94} frequency decreases **Prediction (1 point)** Between 13 and 16 percent (or a selected value between 13 and 16 percent)
(c)	 **Describe effect of LAP^{94} activity (1 point)** • LAP^{94} increases osmolarity/solute concentration of the cytosol • LAP^{94} decreases water potential of the cytosol **Describe function of LAP^{94} in maintaining water balance (1 point)** Prevents water loss to the environment
(d)	 **Explanation (1 point)** • Mussels with *lap*^{94} allele are more likely to survive in high salinity/less likely to survive in low salinity. • Mussels without *lap*^{94} allele are less likely to survive in high salinity/more likely to survive in low salinity. **Prediction (1 point)** • Mussel population will increase in high salinity. • Mussel population will decline in low salinity. **Justification (1 point)** • Mussels in high salinity with *lap*^{94} allele will osmoregulate. • Mussels in low salinity with *lap*^{94} allele will not osmoregulate.
Scoring Statistics	
Mean: 5.20	Standard Deviation: 2.01

2015 #2

Course Content	Practice and Skill
3.5: Cellular Respiration • 3.5.A: Describe the processes and structural features of mitochondria that allow organisms to use energy stored in biological macromolecules. • 3.5.B: Explain how cells obtain energy from biological macromolecules in order to power cellular functions. 7.6: Evidence of Evolution • 7.6.B: Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time. 8.2: Energy Flow Through Ecosystems • 8.2.C: Explain how changes in energy availability affect populations, communities, and ecosystems.	1.A: Describe biological concepts and processes. 2.A: Describe characteristics of visual representations of biological concepts and processes. 5.A: Perform mathematical calculations 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

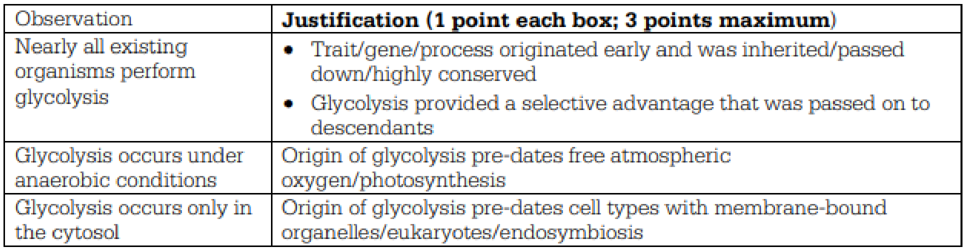
Part	Scoring Guidelines

(a)



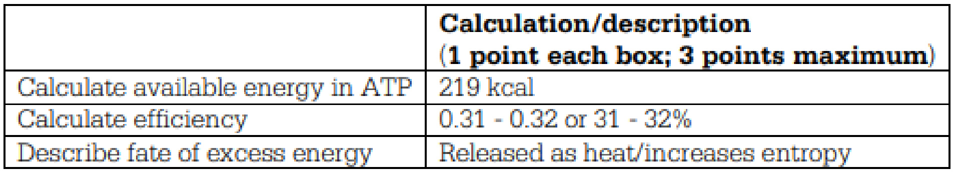
Process	**Description (1 point each box; 3 points maximum)**
Catabolism of glucose in glycolysis and pyruvate oxidation	- Produces NADH for use in ETC - Produces acetyl-CoA for entry into Krebs cycle - Provides energy for (substrate level) phosphorylation of ADP
Oxidation of intermediates in the Krebs cycle	- Produces NADH or FADH2 for use in ETC - Releases high energy electrons for use in ETC - Provides energy to pump protons against their concentration gradient - Produces GTP for (substrate level) phosphorylation of ADP
Formation of a proton gradient by the electron transport chain	- The flow of protons through membrane-bound ATP synthase generates ATP - Provides energy for (oxidative) phosphorylation of ADP

(b)



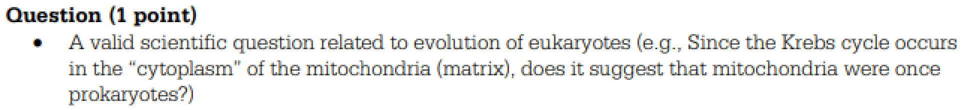
Observation	**Justification (1 point each box; 3 points maximum)**
Nearly all existing organisms perform glycolysis	- Trait/gene/process originated early and was inherited/passed down/highly conserved - Glycolysis provided a selective advantage that was passed on to descendants
Glycolysis occurs under anaerobic conditions	Origin of glycolysis pre-dates free atmospheric oxygen/photosynthesis
Glycolysis occurs only in the cytosol	Origin of glycolysis pre-dates cell types with membrane-bound organelles/eukaryotes/endosymbiosis

(c)



	Calculation/description (1 point each box; 3 points maximum)
Calculate available energy in ATP	219 kcal
Calculate efficiency	0.31 - 0.32 or 31 - 32%
Describe fate of excess energy	Released as heat/increases entropy

(d)



Question (1 point)

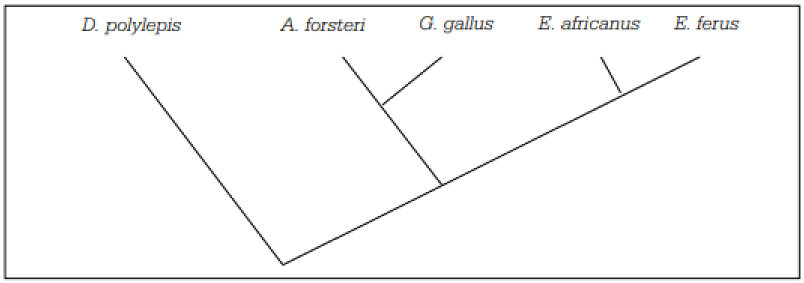
- A valid scientific question related to evolution of eukaryotes (e.g., Since the Krebs cycle occurs in the "cytoplasm" of the mitochondria (matrix), does it suggest that mitochondria were once prokaryotes?)

Scoring Statistics	
Mean: 2.89	Standard Deviation: 2.57

2015 #3

Course Content	Practice and Skill
7.8: Continuing Evolution - 7.8.A: Explain how evolution is an ongoing process in all living organisms. 7.9: Phylogeny - 7.9.B: Explain how phylogenetic trees and cladograms can be used to infer evolutionary relatedness.	2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.A: Make a scientific claim.

Part	Scoring Guidelines

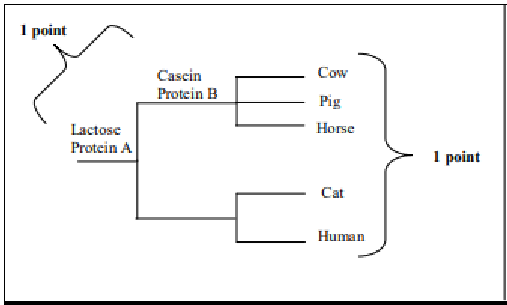
(a)	**Phylogenetic tree (1 point)** NOTE: There can be free rotation around the nodes in the tree.  D. polylepis A. forsteri G. gallus E. africanus E. ferus **Reasoning (1 point)** - D. polylepis has the most differences in amino acids (or changes in DNA or proteins as they relate to amino acids).
(b)	**Identification (1 point)** - Amino acid/molecular data **Reasoning (1 point)** - Morphology may be similar (due to convergent evolution/analogous structures) even if there are differences in amino acid/DNA sequences. - Molecular data (e.g. amino acid changes, DNA changes) directly show genetic make-up/ reveal evolution. OR **Identification (1 point)** - Morphological data **Reasoning (1 point)** - Similar molecular sequences may result in different morphologies. - An example of species with similar proteins but different morphology (e.g., chimps and humans).

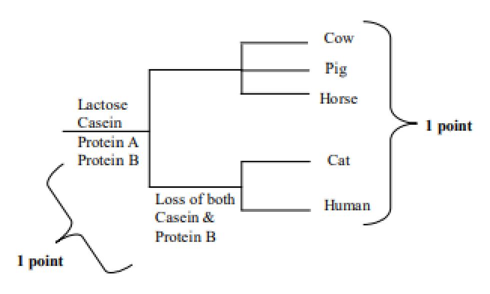
Scoring Statistics	
Mean: 1.90	Standard Deviation: 1.41

2014 #2	
Course Content	Practice and Skill
7.9: Phylogeny • 7.9.A: Describe the types of evidence that can be used to infer an evolutionary relationship.	2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.
Part	Scoring Guidelines

(a)

NOTE: Points are earned in one column only.





Justification (**1 point**)	Justification (**1 point**)
Lactose and Protein A arose in a common ancestor to all 5 animals. Protein B and Casein arose only in the common ancestor to the pig/cow/horse clade/branch.	Lactose, Casein, Protein A, and Protein B arose in a common ancestor to all 5 animals. Protein B and Casein were lost in the common ancestor to the cat/human clade/branch.

(b)

Description (**1 point each; 4 points maximum**)
- Endocytosis of antigen by dendritic cell/macrophage/B-cell
- Degradation of antigen
- Antigen complexed with MHC molecule
- Presentation of antigen on surface of cell
- Recognition of antigen on surface of antigen presenting cell by (helper) T-cell
- Activation of signal transduction mechanism in T-cell
- Activation of (helper) T-cell
- (Helper) T-cells release chemicals that recruit/activate B-cells
- Antigen recognition by B-cell
- Activation of signal transduction mechanism in B-cell
- Activated B-cell or T-cell will clone itself
- Plasma cells/B-cells produce antibodies
- Antibodies recognize antigen
- Antibody binding to antigen is specific
- Memory B cells/memory helper T cells are produced

Prediction (**1 point**)
- Results in more rapid immune response
- Presence of memory cells
- Greater production of antibodies
- Antibodies circulate longer
- Antibodies have a greater affinity for the antigen

(c)

NOTE: Points are earned in a single row only.

Prediction (**1 point**)	Justification (**1 point**)
Infant will be protected/not get sick	Antibodies are passed to infant *in utero*/via breast milk/infant receives B-cells in breast milk
Infant will become sick/die	Insufficient antibodies were transferred to the offspring/infant exposed to high infecting dose of the pathogen

Scoring Statistics	
Mean: 4.62	Standard Deviation: 2.72

2014 #8

Course Content	Practice and Skill
5.2: Meiosis and Genetic Diversity • 5.2.A: Explain how the process of meiosis generates genetic diversity. 6.7: Mutations	1.A: Describe biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

• 6.7.B: Explain how changes in genotype may result in changes in phenotype. 6.8: Biotechnology • 6.8.A: Explain the use of genetic engineering techniques in analyzing or manipulating DNA. 7.4: Population Genetics • 7.4.A: Explain how random occurrences affect the genetic makeup of a population.	

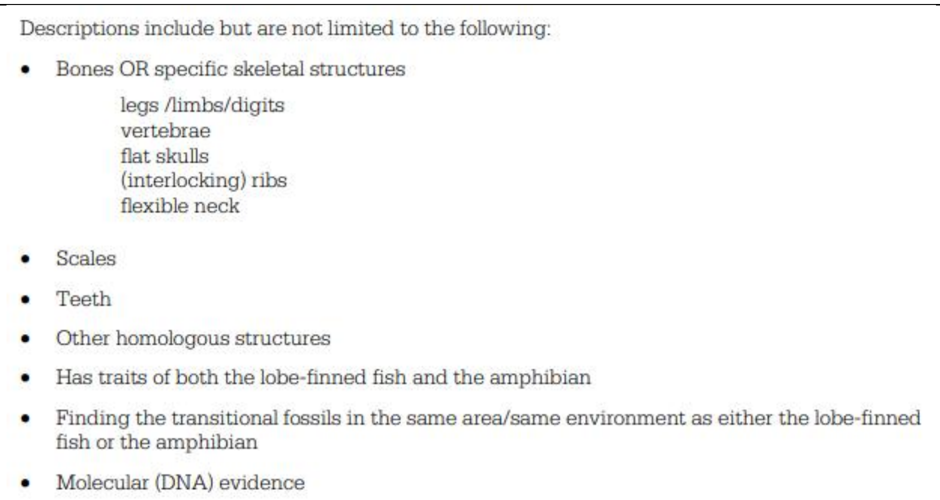
Part	Scoring Guidelines
(a)	Piece of evidence • New phenotypes • Different DNA sequence • New genotypes • Chromosomal differences • Different mRNA sequence • Protein with different amino acid sequence
(b)	Describe mechanism • Sexual reproduction produces offspring with new combinations of alleles/traits • Meiosis produces new combinations of alleles/traits • Crossing over produces new combinations of alleles/traits • Independent assortment produces new combinations of alleles/traits • Random fertilization produces new combinations of alleles/traits • Immigration/gene flow introduces new alleles/gene sequences • Viral infection inserts DNA into genome • Nondisjunction causes anomaly in chromosome number • Chromosomal rearrangements (e.g., large deletions, duplications, translocations, inversions, transposons, etc.) inactivate genes or result in multiple copies of genes • Radiation or chemicals or mutagens induce mutations/changes in DNA
(c)	Description • Genetic variation is the basis of phenotypic variation that can be acted upon by natural selection • Without genetic variation, there is no phenotypic variation on which natural selection can act

Scoring Statistics	
Mean: 1.19	Standard Deviation: 1.03

2013 #3

Course Content	Practice and Skill
7.6: Evidence of Evolution • 7.6.A: Describe the types of data that provide evidence for evolution. • 7.6.B: Explain how morphological, biochemical, and geological data provide evidence that organisms have changed over time.	1.A: Describe biological concepts and processes. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	• Selection: Rocks from 370 MYA sample. • Justification: Transitional fossils are found between 380 MYA (when lobe-finned fishes lived) and 363 MYA (when amphibians appeared) OR between different strata/layers in the correct order.

<table>
<tr><td>(b)</td><td>
Descriptions include but are not limited to the following:
• Bones OR specific skeletal structures
    legs /limbs/digits
    vertebrae
    flat skulls
    (interlocking) ribs
    flexible neck
• Scales
• Teeth
• Other homologous structures
• Has traits of both the lobe-finned fish and the amphibian
• Finding the transitional fossils in the same area/same environment as either the lobe-finned fish or the amphibian
• Molecular (DNA) evidence</td></tr>
<tr><td colspan="2">Scoring Statistics</td></tr>
<tr><td>Mean: 2.55</td><td>Standard Deviation: 1.08</td></tr>
</table>

Unit 8: Ecology

8.1 Responses to the Environment	**8.1.A:** Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment. **8.1.B:** Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.
8.2 Energy Flow Through Ecosystems	**8.2.A:** Describe the strategies organisms use to acquire and use energy. **8.2.B:** Explain how energy flows and matter cycles through trophic levels. **8.2.C:** Explain how changes in energy availability affect populations, communities, and ecosystems. **8.2.D:** Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.
8.3 Population Ecology	**8.3.A:** Describe factors that influence growth dynamics of populations.
8.4 Effect of Density of Populations	**8.4.A:** Explain how the density of a population affects and is determined by resource availability in the environment.
8.5 Community Ecology	**8.5.A:** Describe the structure of a community according to its species composition and diversity. **8.5.B:** Explain how interactions within and among populations influence community structure.
8.6 Biodiversity	**8.6.A:** Describe the relationship between ecosystem diversity and its resilience to changes in the environment. **8.6.B:** Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.
8.7 Disruptions in Ecosystems	**8.7.A:** Explain the interaction between the environment and random or preexisting variations in populations. **8.7.B:** Explain how invasive species affect ecosystem dynamics. **8.7.C:** Describe human activities that lead to changes in ecosystem structure and dynamics. **8.7.D:** Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.

Additional Resources
Unit 8 Review Video
CED Topic TikToks
Topic TikToks
Wayground Game Codes

Topic 8.1 Responses to the Environment

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.</td></tr>
<tr><td>8.1.A.1: Organisms respond to changes in their environment through behavioral and physiological mechanisms.
⌧ EXCLUSION STATEMENT: <i>Knowledge of specific behavioral or physiological mechanisms is beyond the scope of the AP Exam.</i></td><td>☐ I can explain behavioral responses of an organism related to changes in its internal or external environment.
☐ I can explain physiological responses of an organism related to changes in its internal or external environment.</td></tr>
</table>

1. Describe a behavioral response of an organism related to a change in its internal environment.
2. Describe a behavioral response of an organism related to a change in its external environment.
3. Describe a physiological response of an organism related to a change in its internal environment.
4. Describe a physiological response of an organism related to a change in its external environment.

NOTE: Knowing a specific response is outside of scope, so these questions are to help you connect the behavioral or physiological response to the internal/external cue

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.</td></tr>
<tr><td>8.1.A.2: Organisms exchange information with one another in response to internal changes and external cues, which can change behavior.</td><td>☐ I can explain ways organisms exchange information with one another in response to internal changes.
☐ I can explain ways organisms exchange information with one another in response to external cues.
☐ I can explain ways an organism’s behaviors change due to internal cues.
☐ I can explain ways an organism’s behaviors change due to external cues.</td></tr>
</table>

5. Identify two behavioral changes in an organism due to an internal cue.
6. Identify two behavioral changes in an organism due to an external cue.
7. How does an organism’s responses to internal changes or external cues change their behavior?

AP Biology Exam Review

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">8.1.B: Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.</td></tr>
<tr><td>8.1.B.1: Organisms communicate through various mechanisms (visual, audible, tactile, electrical, and/or chemical signals).
I. Organisms have a variety of signaling behaviors that produce changes in the behavior of other organisms and can result in differential reproductive success.
II. Animals use signals to indicate dominance, find food, establish territory, and ensure reproductive success.
☒ EXCLUSION STATEMENT:
<i>Knowledge of specific mechanisms of communication is beyond the scope of the AP Exam.</i></td><td>☐ I can explain ways the behavioral responses of organisms affect their overall fitness
☐ I can explain ways the behavioral responses of organisms affect the success of the population
☐ I can describe that individuals communicate with others.
☐ I can describe signaling behavior that results in differential reproductive success
☐ I can describe ways animals communicate
☐ I can describe functions of animal communication</td></tr>
</table>

8. What is differential reproductive success?
9. How does communication result in differential reproductive success?
10. What are the five types of signals individuals use to communicate with others?
11. Describe the environment where each type is favorable.
12. What is the function of animal communication?

<table>
<tr><th colspan="2">Information Storage and Transmission:
Living systems store, retrieve, transmit, and respond to information essential to life processes.</th></tr>
<tr><td colspan="2">8.1.B: Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.</td></tr>
<tr><td>8.1.B.2: Responses to information and communication of information are vital to natural selection and evolution.
I. Fitness favors innate and learned behaviors that increase survival and reproductive success.
II. Cooperative behavior tends to increase the fitness of the individual and the survival of the population.
☒ EXCLUSION STATEMENT:</td><td>☐ I can describe innate behaviors
☐ I can describe learned behaviors
☐ I can describe innate and learned behaviors that increase survival and reproductive success
☐ I can describe ways cooperative behaviors increase the fitness of the individual
☐ I can describe ways cooperative behaviors increase the fitness of the population</td></tr>
</table>

The details of the various communications and community behavioral systems are beyond the scope of the AP Exam	

13. What is an innate behavior?
14. What is a learned behavior?
15. What type of behaviors does natural selection favor?
16. What is cooperative behavior?
17. How does cooperative behavior increase the fitness of an individual and the survival of the population?
18. What is altruism?
19. How does altruism increase the population's reproductive fitness?

Topic 8.2 Energy Flow Through Ecosystems

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.A: Describe the strategies organisms use to acquire and use energy.</td></tr>
<tr><td>8.2.A.1: Organisms use energy to organize, grow, reproduce, and maintain homeostasis.
I. Organisms use different strategies to regulate body temperature and metabolism. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures. Ectotherms lack efficient internal mechanisms for maintaining body temperature, although they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals.
II. A net gain in energy results in energy storage, the growth of an organism, and increased reproductive output.
III. A net loss of energy results in loss of mass, a decrease in reproductive output, and, eventually, the death of an organism.</td><td>☐ I can describe the strategies organisms use to acquire and use energy.
☐ I can describe ways organisms use energy to regulate body temperature.
☐ I can describe endothermic.
☐ I can describe ways endotherms regulate their body temperature.
☐ I can describe ectothermic.
☐ I can describe ways ectotherms regulate their body temperature.
☐ I can describe the result of a net gain in energy on energy storage.
☐ I can describe the result of a net gain in energy on growth of an organism.
☐ I can describe the result of a net gain in energy on reproductive output.
☐ I can describe the result of a net loss of energy on mass of organisms.
☐ I can describe the result of a net loss of energy on reproductive output.
☐ I can describe the result of a net loss of energy on survival of an organism.</td></tr>
</table>

1. What is an endotherm?
    a. How do endotherms regulate their body temperature?
2. What is an ectotherm?
    a. How do ectotherms regulate their body temperature?
3. Which organism requires more food consumption in a cooler environment? ENDOTHERM or ECTOTHERM
4. How would temperature affect oxygen consumption in an endotherm?
5. What does a net gain in energy result in for an organism?
6. Describe how organisms store energy.
7. What does a net loss in energy result in for an organism?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.A: Describe the strategies organisms use to acquire and use energy.	
8.2.A.2: Different organisms use various reproductive strategies in response to energy availability. Some organisms alternate between asexual and sexual reproduction in response to energy availability.	☐ *I can describe ways organisms use different reproductive strategies in response to energy availability.* ☐ *I can describe alternation of generations.* ☐ *I can describe reproductive differences based on energy availability.*

8. Contrast reproductive strategies of organisms in an environment with high vs low available energy.
9. Describe two different organisms and their reproductive strategies in a low energy available environment.
10. How does an organism alternate between asexual and sexual reproduction?
11. Describe what would cause an organism to alternate from sexual to asexual reproduction.
12. Describe what would cause an organism to alternate from asexual to sexual reproduction.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.1: Ecological levels of organization include populations, communities, ecosystems, and biomes.	☐ *I can describe the ecological levels of organization.*

13. What are the ecological levels of organization?
14. Describe the hierarchy of the ecological levels of organization.
15. How do the ecological levels of organization interact?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.2: Energy flows through ecosystems, while matter and nutrients cycle between the environment and organisms via biogeochemical cycles. The cycles are essential for life, and each cycle demonstrates the conservation of matter. The cycles are interdependent.	☐ *I can explain how energy flows through trophic levels.* ☐ *I can explain how matter cycle through trophic levels.*

16. Describe the path of energy through an ecosystem.
17. How do matter move between the environment and organisms?
18. How do nutrients move between the environment and organisms?

19. What does a biogeochemical cycle demonstrate?
20. TRUE or FALSE: The biogeochemical cycles are not dependent.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.3: Biogeochemical cycles include abiotic and biotic reservoirs, as well as processes that cycle matter between reservoirs.	☐ I can describe biogeochemical cycle reservoirs. ☐ I can describe how matter cycles in biogeochemical cycles.

21. Identify FOUR abiotic reservoirs (aka identify ONE in each of the FOUR biogeochemical cycles)
22. Identify FOUR biotic reservoirs (aka identify ONE in each of the FOUR biogeochemical cycles)
23. Describe how materials move between abiotic and biotic reservoirs.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.4: The hydrologic (water) cycle involves water movement and storage within the hydrosphere. Reservoirs include oceans, surface water, the atmosphere, and living organisms. Processes include evaporation, condensation, precipitation, and transpiration.	☐ I can describe the hydrologic cycle. ☐ I can describe reservoirs in the hydrologic cycle. ☐ I can describe processes involved in the hydrologic cycle.

24. Diagram the hydrologic (water) cycle including the following components: **reservoirs** (oceans, surface water, the atmosphere, and living organisms) AND **processes** (evaporation, condensation, precipitation, and transpiration).
25. What is evaporation?
    a. How does evaporation allow water movement in the hydrologic cycle?
26. What is condensation?
    a. How does condensation allow water movement in the hydrologic cycle?
27. What is precipitation?
    a. How does precipitation allow water movement in the hydrologic cycle?
28. What is transpiration?
    a. How does transpiration allow water movement in the hydrologic cycle?
29. Identify FOUR reservoirs for water storage in the hydrologic cycle.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.5: The carbon cycle involves recycling carbon atoms through Earth's biosphere into organisms as carbohydrates and back into the atmosphere as carbon dioxide (CO_2). At the highest levels of organization, the carbon cycle can be simplified into four parts: photosynthesis, cellular respiration, decomposition, and combustion.	☐ I can describe the carbon cycle. ☐ I can describe reservoirs in the carbon cycle. ☐ I can describe processes involved in the carbon cycle.

30. Diagram the carbon cycle including the following components: reservoirs (organisms, carbohydrates, carbon dioxide and the atmosphere) AND processes (photosynthesis, cellular respiration, decomposition, and combustion)
31. What is photosynthesis?
    a. How does photosynthesis allow carbon movement in the carbon cycle?
32. What is cellular respiration?
    a. How does cellular respiration allow carbon movement in the carbon cycle?
33. What is decomposition?
    a. How does decomposition allow carbon movement in the carbon cycle?
34. What is combustion?
    a. How does combustion allow carbon movement in the carbon cycle?
35. Identify TWO reservoirs for carbon storage in the carbon cycle.
36. Which macromolecules include carbon?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.2.B: Explain how energy flows and matter cycles through trophic levels.	
8.2.B.6: The nitrogen cycle involves several steps, including nitrogen fixation, assimilation, ammonification, nitrification, and denitrification. These steps are performed by microorganisms in the soil. The largest reservoir of nitrogen is the atmosphere. In nitrogen fixation, nitrogen gas (N_2) is fixed into ammonia (NH_3), which ionizes to ammonium (NH_4^+) by acquiring hydrogen ions from the soil solution.	☐ I can describe the nitrogen cycle. ☐ I can describe reservoirs in the nitrogen cycle. ☐ I can describe processes involved in the nitrogen cycle.

37. Diagram the nitrogen cycle including the following components: reservoirs (atmosphere, nitrogen gas, ammonia, ammonium, and microorganisms) AND processes (nitrogen fixation, assimilation, ammonification, nitrification, and denitrification)

38. What is nitrogen fixation?
    a. How does nitrogen fixation allow nitrogen movement in the nitrogen cycle?
39. What is assimilation?
    a. How does assimilation allow nitrogen movement in the nitrogen cycle?
40. What is ammonification?
    a. How does ammonification allow nitrogen movement in the nitrogen cycle?
41. What is nitrification?
    a. How does nitrification allow nitrogen movement in the nitrogen cycle?
42. What is denitrification?
    a. How does denitrification allow nitrogen movement in the nitrogen cycle?
43. Identify the pathway of nitrogen containing molecules in nitrogen fixation.
44. Which macromolecules include nitrogen?

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.B: Explain how energy flows and matter cycles through trophic levels.</td></tr>
<tr><td>8.2.B.7: The phosphorus cycle involves weathering rocks releasing phosphate (PO_4^{3-}) into soil and groundwater. Producers take in phosphate, which is incorporated into biological molecules; consumers eat producers, transferring phosphate to animals. Phosphorus returns to the soil via decomposition of biomass, or excretion. Phosphate can also be incorporated back into the environment via decomposition of decaying organic matter</td><td>☐ I can describe the phosphorus cycle.
☐ I can describe reservoirs in the phosphorus cycle.
☐ I can describe processes involved in the phosphorus cycle.</td></tr>
</table>

45. Diagram the phosphorus cycle including the following components: reservoirs (rocks, phosphate, soil, groundwater, animals) AND process (weathering, heterotrophy, decomposition, and excretion).
46. What is weathering?
47. How does weathering allow phosphorus movement in the phosphorus cycle?
48. Describe how biological molecules with phosphorus are transferred from producers to animals.
49. What is decomposition?
50. How does decomposition allow phosphorus movement in the phosphorus cycle?
51. What is excretion?
52. How does excretion allow phosphorus movement in the phosphorus cycle?
53. Which macromolecules include phosphorus?

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.C: Explain how changes in energy availability affect populations, communities, and ecosystems.</td></tr>
<tr><td>8.2.C.1: Changes in energy availability can result in changes in population size.</td><td>☐ I can explain ways changes in energy availability affect populations and ecosystems.
☐ I can explain the result of a change in energy availability on population size.</td></tr>
</table>

54. Describe the function of energy in an organism.
55. How does a change in energy available affect population size?

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.C: Explain how changes in energy availability affect populations, communities, and ecosystems.</td></tr>
<tr><td>8.2.C.2: Changes in energy availability can result in disruptions to an ecosystem.
I. A change in energy resources such as sunlight can affect the number and size of the trophic levels. Trophic levels include producers; primary, secondary, tertiary, and quaternary consumers; and decomposers.
II. A change in the biomass or number of producers in a given geographic area can affect the number and size of other trophic levels.</td><td>☐ I can explain the result of a change in energy availability on ecosystem.
☐ I can explain the effect of a change in sunlight on number and size of trophic levels.
☐ I can explain the effect of a change in biomass or number of producers on the number and size of other trophic levels.</td></tr>
</table>

56. Describe what each trophic level includes.
57. How does a decrease in sunlight affect the number and sizes of each trophic level?
58. How does an increase in sunlight affect the number and sizes of each trophic level?
59. How does a decrease in producers affect the number and size of other trophic levels?
60. How does an increase in producers affect the number and size of other trophic levels?

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.D: Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.</td></tr>
<tr><td>8.2.D.1: Autotrophs capture energy from physical or chemical sources in the environment.
I. Photosynthetic organisms capture energy present in sunlight contributing to primary productivity.</td><td>☐ I can explain ways the activities of autotroph and heterotroph enable the flow of energy within an ecosystem.
☐ I can describe the function of autotrophs in capturing energy.</td></tr>
</table>

II. Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, which can occur in the absence of oxygen.	☐ I can describe ways photosynthetic organisms capture energy. ☐ I can describe ways chemosynthetic organisms capture energy. ☐

61. What is an autotroph?
62. What is the function of an autotroph in capturing energy?
63. How do photosynthetic organisms capture energy?
    a. Identify one example of a photosynthetic organism.
64. How do chemosynthetic organisms capture energy?
    a. Identify one example of a photosynthetic organism.
65. True or False: Oxygen is required for the photosynthetic and chemosynthetic organism to capture energy.

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.2.D: Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.</td></tr>
<tr><td>8.2.D.2: Heterotrophs, which include carnivores, herbivores, omnivores, decomposers, and scavengers, metabolize carbohydrates, lipids, and proteins as sources of energy. Heterotrophs capture the energy present in carbon compounds by consuming organic matter derived from autotrophs incorporating matter into their tissues.</td><td>☐ I can describe the function of heterotrophs in capturing energy.
☐ I can identify a heterotroph’s sources of energy by hydrolysis.</td></tr>
</table>

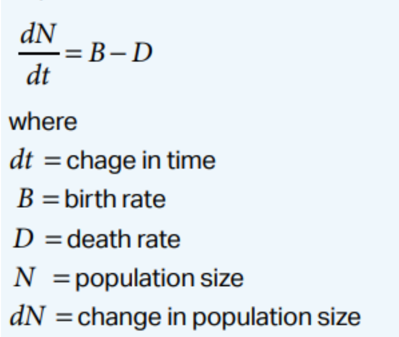
66. What is a heterotroph?
67. Identify which levels of the trophic structure include heterotrophs.
68. What macromolecules can a heterotroph use for sources of energy?
69. Describe where heterotrophs obtain their energy.

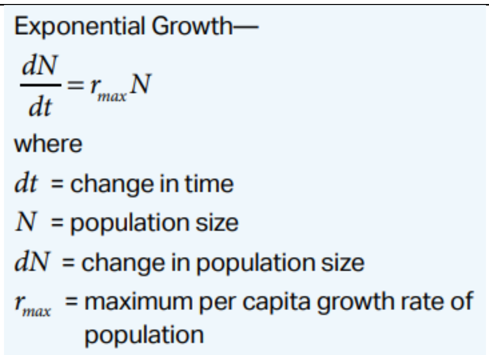
AP Biology Exam Review

Topic 8.3 Population Ecology

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
8.3.A: Describe factors that influence growth dynamics of populations.	
8.3.A.1: Populations comprise individual organisms of the same species that interact with one another and with the environment in complex ways.	☐ I can describe factors that influence growth dynamics of populations. ☐ I can describe ways populations interact with one another. ☐ I can describe ways populations interact with the environment.

1. What makes up a population?
2. How do populations interact with one another?
3. How do populations interact with the environment?

Information Storage and Transmission: Living systems store, retrieve, transmit, and respond to information essential to life processes.	
8.3.A: Describe factors that influence growth dynamics of populations.	
8.3.A.2: Many adaptations in organisms are related to obtaining and using energy and matter in a particular environment. I. Population growth dynamics depend on birth rate, death rate, and population size.  Population Growth— $\frac{dN}{dt} = B - D$ where dt = chage in time B = birth rate D = death rate N = population size dN = change in population size II. Reproduction without constraints results in the exponential growth of a population.	☐ I can describe adaptations for obtaining energy and matter in the environment. ☐ I can describe adaptations for using energy and matter in the environment. ☐ I can describe factors that population growth dynamics depend on. ☐ I can calculate population growth. ☐ I can calculate birth rate (per capita). ☐ I can calculate death rate (per capita). ☐ I can describe exponential growth of a population. ☐ I can describe factors that allow for exponential growth of a population. ☐ I can calculate exponential growth rate. ☐ I can calculate per capita growth rate of a population.

 Exponential Growth— $\frac{dN}{dt} = r_{max}N$ where dt = change in time N = population size dN = change in population size r_{max} = maximum per capita growth rate of population	

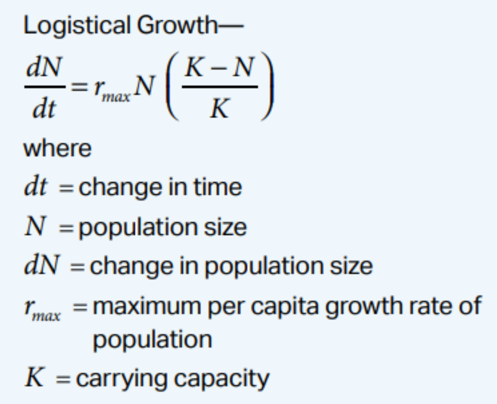
4. Identify two adaptations for obtaining energy and matter in the environment.
5. Identify two adaptations for using energy and matter in the environment.
6. Identify three factors that population growth dynamics depend on.
7. What is population growth?
8. How do you solve for B?
9. How do you solve for D?
10. If a population has 300 individuals, then 20 new individuals are born and 40 individuals die. What is the population growth of this population?
    a. Solve for B
    b. Solve for D
    c. Solve for dN/dt.
11. What is exponential growth?
12. What allows for a population to undergo exponential growth?
13. How do you solve for r?
14. If a population has 300 individuals, then 40 new individuals are born and 20 individuals die. What is the population size after 3 generations?
    a. Solve for r
    b. Solve for dN/dt

AP Biology Exam Review

Topic 8.4 Effect of Density on Populations

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment.</td></tr>
<tr><td>8.4.A.1: Carrying capacity is the sustainable abundance of a species that can be supported by the ecosystem's total available resources.</td><td>☐ I can explain ways the density of a population affects resource availability in the environment.
☐ I can explain ways the density of a population is determined by resource availability in the environment.
☐ I can describe carrying capacity.</td></tr>
</table>

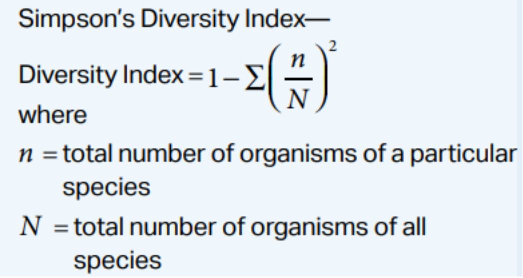
1. What is density?
2. What is carrying capacity?
3. What happens to resource availability as the population size increases?
4. What happens to resource availability as the population size decreases?
5. As resource availability increases, what happens to the population size?
6. As resource availability decreases, what happens to the population size?

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment.</td></tr>
<tr><td>8.4.A.2: As limits to growth attributable to density dependent and density-independent factors are imposed, a logistic growth model typically ensues.

Logistical Growth—
$\frac{dN}{dt} = r_{max} N \left(\frac{K-N}{K} \right)$
where
dt = change in time
N = population size
dN = change in population size
r_{max} = maximum per capita growth rate of population
K = carrying capacity</td><td>☐ I can identify density-dependent factors.
☐ I can identify density-independent factors.
☐ I can describe the effect of density-dependent factors on a population's growth.
☐ I can describe the effect of density-independent factors on a population's growth.
☐ I can calculate logistic growth rate of a population.
☐ I can describe population growth rate as the population size approaches the carrying capacity.</td></tr>
</table>

7. What are density-dependent factors?
    a. Identify three density-dependent factors.
    b. How do density-dependent factors affect a population's growth?

8. What are density-independent factors?
    a. Identify three density-independent factors.
    b. How do density-independent factors affect a population's growth?
9. If a population has 300 individuals and the environment can support 400 individuals, then 50 new individuals are born and 10 individuals die. What is the logistic growth rate of this population?
10. What happens to the growth rate as the population size approaches the carrying capacity?

Topic 8.5 Community Ecology

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.5.A: Describe the structure of a community according to its species composition and diversity</td></tr>
<tr><td>8.5.A.1: The structure of a community is measured and described in terms of species composition and species diversity.

Simpson's Diversity Index—
Diversity Index $= 1 - \Sigma\left(\frac{n}{N}\right)^2$
where
n = total number of organisms of a particular species
N = total number of organisms of all species</td><td>☐ I can describe the structure of a community according to its species composition and diversity.
☐ I can describe ways the structure of a community is measured.
☐ I can describe ways the structure of a community is described in terms of species composition and species diversity.
☐ I can apply Simpson's Diversity Index to a population.
☐ I can describe properties of a diverse population.</td></tr>
</table>

1. How is the structure of a community measured?
2. What is a species?
3. What is species composition?
4. What is species diversity?
5. Identify two properties of a diverse population.
6. Complete the Practice Problem for Simpson's Index (from http://www.countrysideinfo.co.uk/simpsons.htm):
   Calculate the Simpson's Index of a sample from the woods:

Species	Number (n)
Woodrush	2
Holly (seedlings)	8
Bramble	1
Yorkshire Fog	1
Sedge	3
Total (N)	15

<table>
<tr><th colspan="2">Energetics:
Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.</th></tr>
<tr><td colspan="2">8.5.B: Explain how interactions within and among populations influence community structure.</td></tr>
<tr><td>8.5.B.1: Communities are groups of interacting populations of different species that change over time based on the interactions between those populations.</td><td>☐ I can explain ways interactions within and among populations influence community structure.
☐ I can explain ways communities change over time depending on interactions between populations.
☐ I can describe a community.</td></tr>
</table>

7. What is a community?
8. Describe two ways populations interact within a community.

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.5.B: Explain how interactions within and among populations influence community structure.	
8.5.B.2: Interactions among populations determine how they access energy and matter within a community.	☐ I can explain ways interactions among populations determine how they access energy and matter within a community. ☐

9. How do interactions among populations affect their ability to access energy and matter within a community?

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.5.B: Explain how interactions within and among populations influence community structure.	
8.5.B.3: Relationships among interacting populations can be characterized by positive and negative effects and can be modeled. Examples include predator/prey interactions, cooperation, trophic cascades, and niche partitioning.	☐ I can describe positive interactions between populations. ☐ I can describe negative interactions between populations. ☐ I can describe predator/prey interactions. ☐ I can describe trophic cascades. ☐ I can describe niche partitioning. ☐

10. What are positive interactions between populations?
11. What are negative interactions between populations?
12. What is a predator/prey interaction?
13. What is cooperation?
14. What are trophic cascades?
15. What is niche partitioning?
16. Identify the following as positive or negative interactions? Justify.
    a. Predation/prey interactions
    b. Cooperation
    c. Trophic cascades
    d. Niche partitioning

Energetics: Biological systems use energy and molecular building blocks to grow, reproduce, and maintain dynamic homeostasis.	
8.5.B: Explain how interactions within and among populations influence community structure.	
8.5.B.4: Competition, predation, and symbioses, including parasitism, mutualism, and commensalism, can drive population dynamics.	☐ I can explain ways competition drives population dynamics. ☐ I can explain ways predation drives population dynamics. ☐ I can explain ways symbioses drives population dynamics. ☐ I can explain ways parasitism drives population dynamics. ☐ I can explain ways mutualism drives population dynamics. ☐ I can explain ways commensalism drives population dynamics.

17. What is competition?
    a. How does competition drive population dynamics?
18. What is predation?
    a. How does predation drive population dynamics?
19. Identify the three types of symbiosis.
20. What is parasitism?
    a. How does parasitism drive population dynamics?
21. What is mutualism?
    a. How does mutualism drive population dynamics?
22. What is commensalism?
23. How does commensalism drive population dynamics?

Topic 8.6 Biodiversity

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment.	
8.6.A.1: Natural and artificial ecosystems with fewer component parts, and with little diversity among the parts, are often less resilient to changes in the environment.	☐ I can describe the relationship between ecosystem diversity and its resilience to changes in the environment. ☐ I can describe the effect of fewer components and little diversity among the parts.

1. In terms of component parts and diversity, what type of ecosystem is more resilient to changes in the environment?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment.	
8.6.A.2: Keystone species, producers, and essential abiotic and biotic factors contribute to maintaining the diversity of an ecosystem.	☐ I can describe keystone species. ☐ I can describe producers. ☐ I can describe essential abiotic factors. ☐ I can describe essential biotic factors. ☐ I can describe ways keystone species, producers, and essential abiotic/biotic factors maintain diversity of an ecosystem.

2. What are keystone species?
    a. How do they maintain diversity in an ecosystem?
3. What are producers?
    a. How do they maintain diversity in an ecosystem?
4. What are abiotic factors?
    a. What abiotic factors are essential in maintaining the diversity in an ecosystem?
5. What are biotic factors?
    a. What biotic factors are essential in maintaining the diversity in an ecosystem?

<table>
<tr><th colspan="2">Systems Interactions:
Biological systems interact, and these systems and their interactions exhibit complex properties.</th></tr>
<tr><td colspan="2">8.6.B: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.</td></tr>
<tr><td>8.6.B.1: The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem. When they are removed from the ecosystem, it often collapses.</td><td>☐ I can explain ways the addition of any component of an ecosystem will affect its overall short term structures.
☐ I can explain ways the removal of any component of an ecosystem will affect its overall short term structures.
☐ I can explain ways the addition of any component of an ecosystem will affects its long-term structure.
☐ I can explain ways the removal of any component of an ecosystem will affect its long-term structure.
☐ I can describe ways the diversity can influence the organization of ecosystem.
☐ I can describe the effects of keystone species on the ecosystem.
☐ I can describe the effect of removal of keystone species on ecosystems</td></tr>
</table>

6. How does the diversity of a species within an ecosystem influence the organization of the ecosystem?
7. Identify an example of an addition to an ecosystem and its effect…
    a. Short-term structure
    b. Long-term structure
8. Identify an example of a removal from an ecosystem and its effect on…
    a. Short-term structure
    b. Long-term structure
9. Identify a keystone species.
    a. What would occur if this keystone species was removed from the ecosystem?
10. Describe a specific example of a keystone species in an ecosystem and the effects on the ecosystem when it is removed.

Topic 8.7: Disruptions in Ecosystems

Evolution: The process of evolution drives the diversity and unity of life.	
8.7.A Explain the interaction between the environment and random or preexisting variations in populations.	
8.7.A.1 An adaptation is a genetic variation that is favored by selection and manifests as a trait that provides an advantage to an organism in a particular environment.	☐ I can explain the interaction between the environment and random variation in the populations. ☐ I can explain the interaction between the environment and preexisting variations in populations. ☐ I can explain adaptations. ☐ I can explain ways that adaptations are selected in a population. ☐

1. What is an adaptation?
2. How do adaptations get introduced?
3. How are adaptations selected for in a population?

Evolution: The process of evolution drives the diversity and unity of life.	
8.7.A Explain the interaction between the environment and random or preexisting variations in populations.	
8.7.A.2 Heterozygote advantage is when the heterozygous genotype has a higher relative fitness than either the homozygous dominant or homozygous recessive genotype.	☐ I can describe heterozygote advantage. ☐ I can describe the effect of heterozygote advantage on the relative fitness of a population.

4. What is heterozygote advantage?
5. How does heterozygote advantage yield a higher fitness than the homozygous dominant or homozygous recessive genotypes?
6. Provide an example of heterozygote advantage.

Evolution: The process of evolution drives the diversity and unity of life.	
8.7.A Explain the interaction between the environment and random or preexisting variations in populations.	
8.7.A.3 Mutations are not directed by specific environmental pressures.	☐ I can explain where mutations come from. ☐ I can explain that mutations are random with no direction for selective pressures.

7. What is a mutation?
8. Where do mutations come from?
9. TRUE or FALSE: The use of an insecticide causes mutations in the insect leading to resistance of the insecticide.

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
8.7.B Explain how invasive species affect ecosystem dynamics.	
8.7.B.1 The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete native species for resources.	☐ I can explain ways invasive species affect ecosystem dynamics. ☐ I can describe ways invasive species enter an area. ☐ I can describe ways invasive species are able to exploit an area. ☐ I can describe the population growth rate of an invasive species.

11. What is an invasive species?
12. How are invasive species able to exploit an area?
13. What does the population growth rate curve look like?
14. How do invasive species affect ecosystem dynamics?

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
8.7.C Describe human activities that lead to changes in ecosystem structure and dynamics.	
8.7.C.1 Human impact accelerates changes at local and global levels. These activities can drive changes in ecosystems, such as the following, that cause extinctions to occur: I. Biomagnification II. Eutrophication	☐ I can describe human activities that lead to changes in ecosystem structure and dynamics. ☐ I can describe the effect of human activities on local and global levels. ☐ I can describe changes in ecosystems from human impact. ☐ I can describe biomagnification. ☐ I can describe eutrophication.

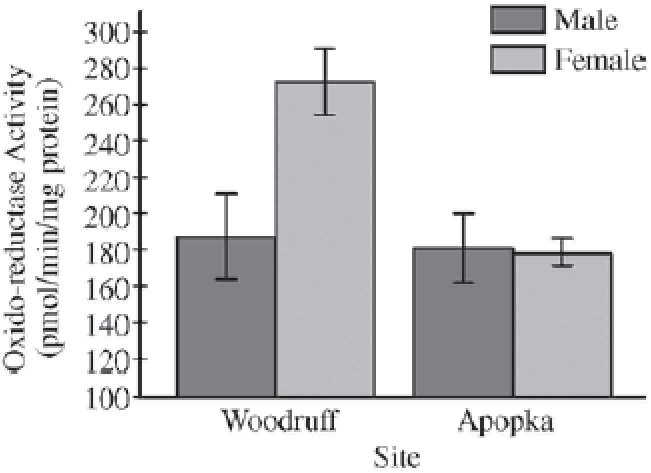
15. What is a local ecosystem?
16. What is a global ecosystem?
17. How does the distribution of an ecosystem change over time?
18. What is biomagnification?
    a. How does biomagnification impact an ecosystem?
19. What is eutrophication?
    a. How does eutrophication impact an ecosystem?
20. Describe how human impact affects an ecosystem.

Systems Interactions: Biological systems interact, and these systems and their interactions exhibit complex properties.	
8.7.D Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.	
8.7.D.1 Geological and meteorological events affect habitat change and ecosystem distribution. Biogeographical studies illustrate these changes.	☐ I can explain ways geological activity leads to changes in ecosystem structure. ☐ I can explain ways meteorological activity leads to changes in ecosystem structure. ☐ I can explain ways geological activity leads to changes in ecosystem dynamics. ☐ I can explain ways meteorological activity leads to changes in ecosystem dynamics.

21. How do geological events affect habitat change and ecosystem distribution?
22. What is biogeography?
23. How did the habitats and ecosystems change when Pangaea split apart?

Multiple Choice Practice

1. Testosterone oxido-reductase is a liver enzyme that regulates testosterone levels in alligators. One study compared testosterone oxido-reductase activity between male and female alligators from Lake Woodruff, a relatively pristine environment, and from Lake Apopka, an area that has suffered severe contamination. The graph above depicts the findings of that study.

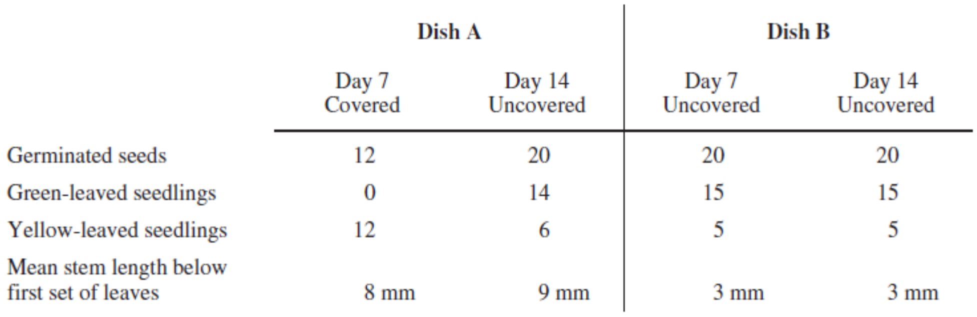


The data in the graph best support which of the following claims?

a. Environmental contamination elevates total testosterone oxido-reductase activity in females.
b. Environmental contamination reduces total testosterone oxido-reductase activity in females.
c. Environmental contamination elevates total testosterone oxido-reductase activity in males.
d. Environmental contamination reduces total testosterone oxido-reductase activity in males.

Use the following information to answer question 2.

A student placed 20 tobacco seeds of the same species on moist paper towels in each of two petri dishes. Dish A was wrapped completely in an opaque cover to exclude all light. Dish B was not wrapped. The dishes were placed equidistant from a light source set to a cycle of 14 hours of light and 10 hours of dark. All other conditions were the same for both dishes. The dishes were examined after 7 days and the opaque cover was permanently removed from dish A. Both dishes were returned to the light and examined again at 14 days. The following data were obtained.



	Dish A		Dish B	
	Day 7 Covered	Day 14 Uncovered	Day 7 Uncovered	Day 14 Uncovered
Germinated seeds	12	20	20	20
Green-leaved seedlings	0	14	15	15
Yellow-leaved seedlings	12	6	5	5
Mean stem length below first set of leaves	8 mm	9 mm	3 mm	3 mm

2. The most probable cause for the difference in mean stem length between plants in dish A and plants in dish B is which of the following?
    a. Shortening of cells in the stem in response to the lack of light
    b. Elongation of seedlings in response to the lack of light
    c. Enhancement of stem elongation by light
    d. Genetic differences between the seeds

3. Which of the following statements most directly supports the claim that different species of organisms use different metabolic strategies to meet their energy requirements for growth, reproduction, and homeostasis?
    a. During cold periods pond-dwelling animals can increase the number of unsaturated fatty acids in their cell membranes while some plants make antifreeze proteins to prevent ice crystal formation in tissues.
    b. Bacteria lack introns while many eukaryotic genes contain many of these intervening sequences.
    c. Carnivores have more teeth that are specialized for ripping food while herbivores have more teeth that are specialized for grinding food.
    d. Plants generally use starch molecules for storage while animals use glycogen and fats for storage.

4. Figure I shows the growth of an algal species in a flask of sterilized pond water. If phosphate is added as indicated, the growth curve changes as shown in Figure II.

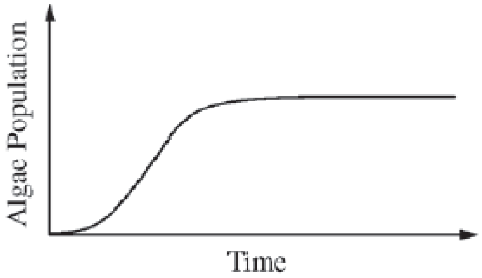


Figure I

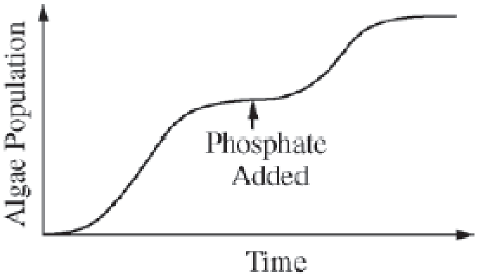
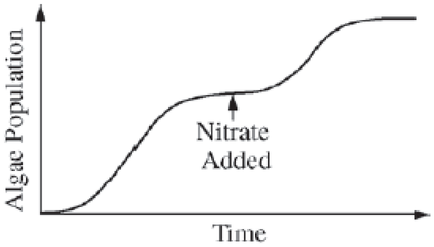
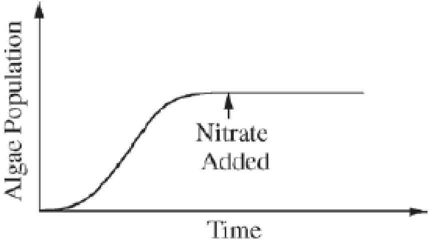


Figure II

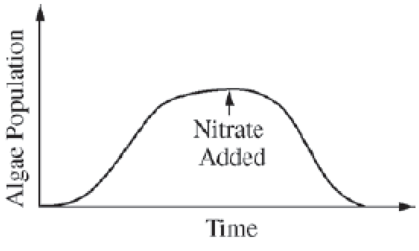
Which of the following is the best prediction of the algal growth if nitrate is added instead of phosphate?



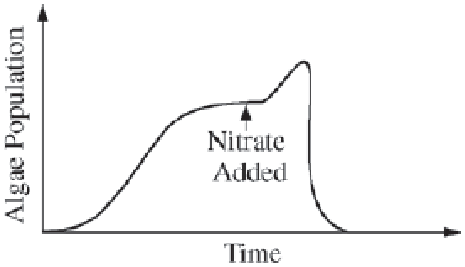
a.



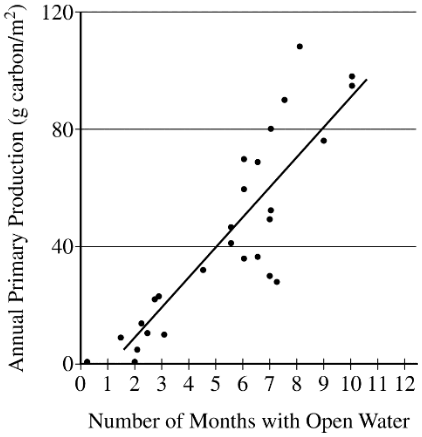
c.



b.



d.



5. In the Arctic Ocean, the predominant primary producers are phytoplankton. Phytoplankton are consumed by zooplankton, which in turn are eaten by codfish. In years when there is more open water (less ice coverage), there are more zooplankton and fish than in years with less open water (more ice coverage). Based on the graph above, the difference is most likely because
   a. when there is less open water, light is blocked from the zooplankton, so they cannot produce as much food for the fish
   b. when there is more open water, the temperature is warmer, so the zooplankton and fish populations increase in size
   c. the ice blocks the light, so in years with more ice coverage, there is less photosynthesis by the phytoplankton
   d. the ice increases the light available for photosynthesis, so primary production increases and zooplankton populations increase in size

Use the following information to answer question 6.

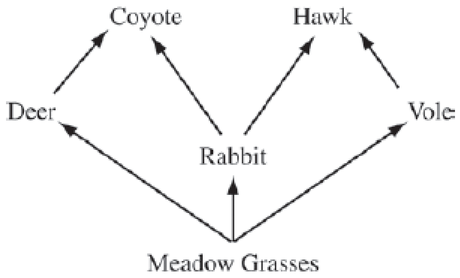
An experiment to measure the rate of respiration in crickets and mice at 10°C and 25°C was performed using a respirometer, an apparatus that measures changes in gas volume. Respiration was measured in mL of O_2 consumed per gram of organism over several five-minute trials and the following data were obtained.

Organism	Temperature (°C)	Average respiration (mL O_2/g/min)
Mouse	10	0.0518
Mouse	25	0.0321
Cricket	10	0.0013
Cricket	25	0.0038

6. According to the data, the crickets at 25°C have greater oxygen consumption per gram of tissue than do the crickets at 10°C. This trend in oxygen consumption is the opposite of that in the mice. The difference in trends in oxygen consumption among crickets and mice is due to their
   a. relative size
   b. mode of nutrition
   c. mode of internal temperature regulation
   d. mode of ATP production

7. Beaked whales feed at various depths, but they defecate at the ocean's surface. Nitrogen-rich whale feces deposited in surface waters supply nutrients for algae that are eaten by surface dwelling fish. Which of the following best predicts what would happen if the whale population decreased?
   a. There would be a reduction in surface nitrogen concentration, which would cause an algal bloom.
   b. The surface fish populations would decline due to reduced populations of algae.
   c. The remaining whales would accumulate mutations at a faster rate.
   d. The remaining whales would be forced to forage in the deepest parts of the ocean.

8. The following is a food web for a meadow habitat that occupies 25.6 km^2. The primary producers' biomass is uniformly distributed throughout the habitat and totals 1,500 kg/km^2.



Developers have approved a project that will permanently reduce the primary producers' biomass by 50 percent and remove all rabbits and deer.

Which of the following is the most likely result at the completion of the project?

   a. The biomass of coyotes will be 6 kg, and the biomass of hawks will be 0.5 kg.
   b. The biomass of coyotes will be dramatically reduced.
   c. The coyotes will switch prey preferences and outcompete the hawks.
   d. There will be 50 percent fewer voles and 90 percent fewer hawks.

Use the following information to answer questions 9-12.

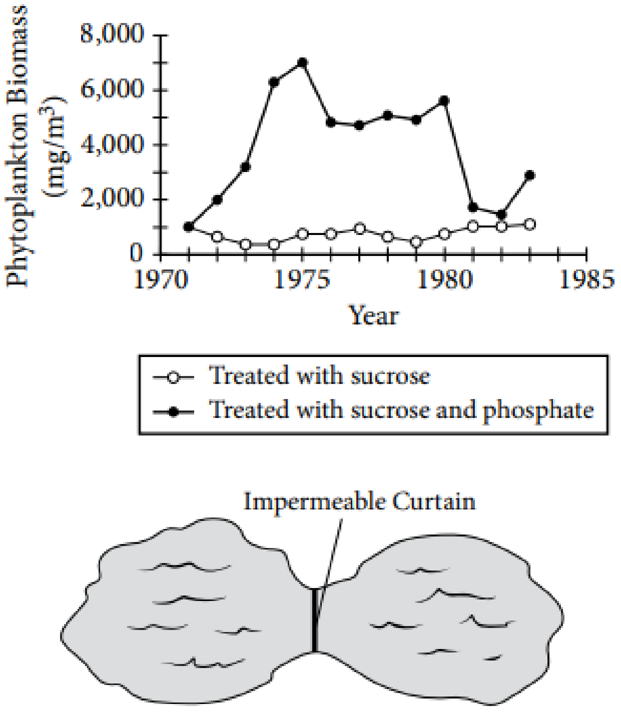


Figure 1. Phytoplankton biomass in two sides of a small lake that is divided by an impermeable curtain

In the early 1970s, researchers hypothesized that carbon was the limiting nutrient in many aquatic ecosystems. To test this hypothesis, the researchers divided a small lake in two roughly equal halves with an impermeable curtain that was fastened and sealed to the bedrock of the lake. Beginning in 1971 the researchers treated one side of the lake with sucrose and the other side with both sucrose and phosphate. From 1971 to 1983 the researchers monitored the phytoplankton biomass in both parts of the lake. The results are shown in Figure 1.

9. Which of the following claims is best supported by the data?
    a. Carbon was a limiting factor for phytoplankton in the lake.
    b. Phosphate was a limiting factor for phytoplankton in the lake.
    c. Both carbon and phosphate were limiting factors for phytoplankton in the lake.
    d. Neither carbon nor phosphate was a limiting factor for phytoplankton in the lake

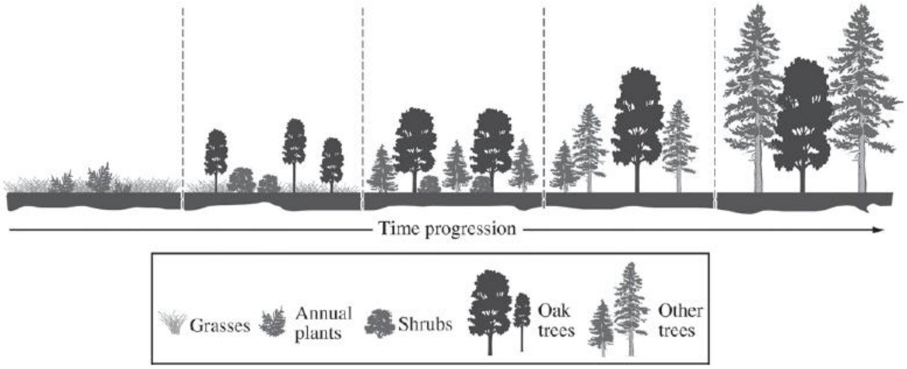
10. The average growth rate of the phytoplankton population from 1971 to 1975 in the side of the lake treated with sucrose and phosphate is closest to which of the following?
    a. 125 (mg/m^3)/year
    b. 1,000 (mg/m^3)/year
    c. 1,500 (mg/m^3)/year
    d. 6,000 (mg/m^3)/year

11. Which of the following treatments would have been the best control treatment for the experiment?
    a. An untreated section of the lake
    b. A section of the lake that was treated with phosphate but not sucrose
    c. A different lake that was treated with sucrose and phosphate
    d. A small pool of the lake water maintained in a controlled laboratory environment

12. Which of the following was most likely a direct consequence of the addition of phosphate to the lake?
    a. The amount of biomass in the first trophic level decreased.
    b. The amount of biomass in the second trophic level decreased.
    c. The amount of energy available to producers in the lake increased.
    d. The amount of energy available to consumers in the lake increased

13. Thrips are insects that feed on rose pollen. Scientists noted that the thrips population increased in the spring and decreased dramatically during the summer. The researchers hypothesized that food abundance was the limiting factor for the population. Which of the following types of data would be most useful for the scientists to collect at regular intervals on a designated test plot of rose plants?
    a. Amount of sunlight (hours/day)
    b. Mean temperature (°C)
    c. Density of rose pollen produced (g/m^2)
    d. Amount of pollen produced by each flower (g/flower)

14. The diagram below shows the progression of ecological events after a fire in a particular ecosystem. Based on the diagram, which of the following best explains why the oak trees are later replaced by other trees?



a. Eventually the other trees grow taller than the oak trees and form a dense canopy that shades the understory.
b. Oak trees alter the pH of the soil, making the forest better suited for shrubs and other trees.
c. Roots of shrubs proliferate in the soil of the forest and prevent the oak trees from obtaining water.
d. Oak trees succumb to environmental pollutants more readily than do either the shrubs or the other trees.

Use the following information to answer questions 15-17.

The figures below show the changes in populations of two species of flour beetles, Tribolium confusum (Figure I) and Tribolium castaneum (Figure II), in cultures without parasites (o) and in cultures infected with a parasite (•). Each data point represents the mean population size from ten culture dishes of equal size and food content.

FIGURE I: NUMBER OF *TRIBOLIUM CONFUSUM* OVER TIME

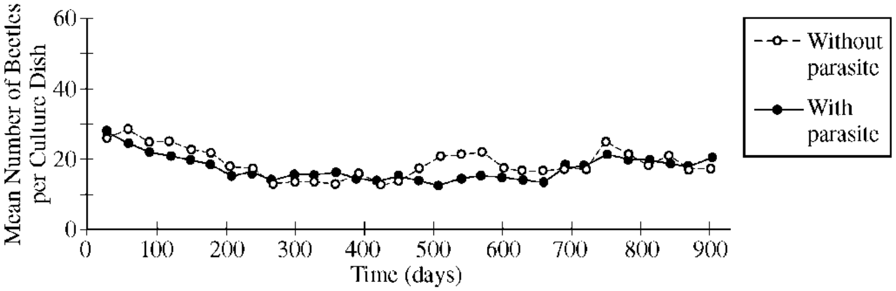
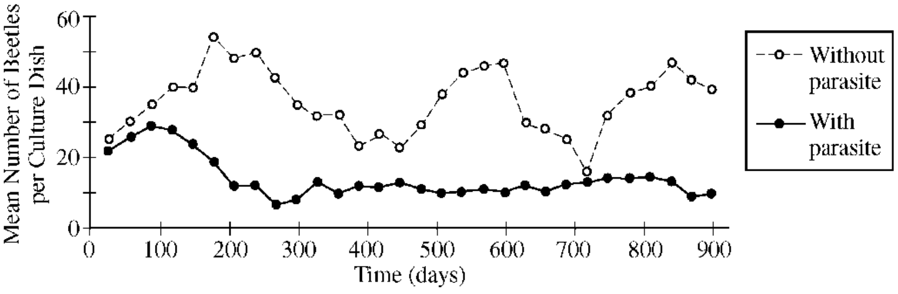


FIGURE II: NUMBER OF *TRIBOLIUM CASTANEUM* OVER TIME



15. Under which of the following conditions is the observed number of beetles per culture dish the greatest?
    a. *T. confusum* with parasite at 500 days
    b. *T. confusum* without parasite at 300 days
    c. *T. castaneum* with parasite at 100 days
    d. *T. castaneum* with parasite at 600 days

16. The data over the duration of the experiment provide the strongest support for which of the following conclusions regarding the effect of the parasite on *Tribolium* populations?
    a. *T. confusum* is adversely affected by the parasite, while *T. castaneum* is not.
    b. *T. castaneum* is adversely affected by the parasite, while *T. confusum* is not.
    c. Both *T. confusum* and *T. castaneum* are adversely affected by the parasite.
    d. Both *T. confusum* and *T. castaneum* show increased fitness in the presence of the parasite.

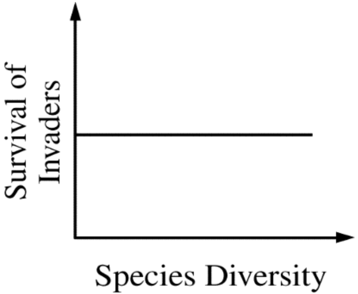
17. In Figure 1, the difference between the two curves can best be attributed to which of the following?
    a. The difference between controlled laboratory conditions and the natural environment
    b. The effect of the host on its parasite
    c. The influence of competition for limited resources
    d. The natural variation among populations

18. If the experiment was continued for an additional 500 days, the population density of *T. castaneum* with the parasite would most likely stabilize at a value closest to which of the following?
    a. 5 beetles/culture dish
    b. 10 beetles/culture dish
    c. 20 beetles/culture dish
    d. 25 beetles/culture dish

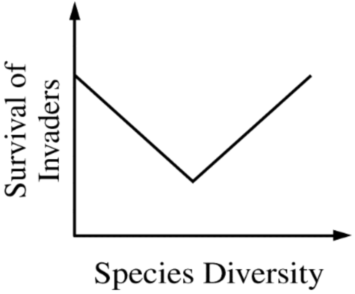
19. A researcher is investigating the relationship between the existing species diversity in a community and the ability of an introduced nonnative species to destabilize the community.

    Which of the following graphs is most consistent with the claim that communities with high diversity are more resistant to change than are communities with low diversity?

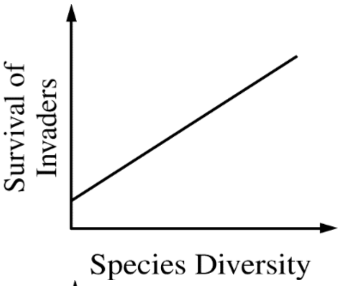
a.



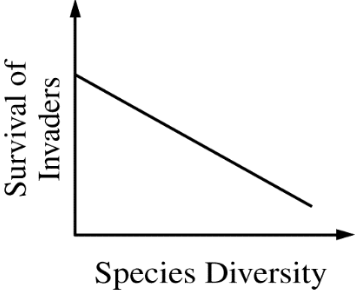
b.



c.



d.



20. Scientists have found that the existing populations of a certain species of amphibian are small in number, lacking in genetic diversity, and separated from each other by wide areas of dry land. Which of the following human actions is most likely to improve the long-term survival of the amphibians?
    a. Cloning the largest individuals to counteract the effects of aggressive predation
    b. Reducing the population size by one-fifth to decrease competition for limited resources
    c. Constructing a dam and irrigation system to control flooding
    d. Building ponds in the areas of dry land to promote interbreeding between the separated populations

21. Which of the following best describes altruistic behaviors?
    a. a defensive behavior in which organisms huddle all together
    b. a selfless behavior to save the population but risk yourself
    c. a protective behavior describing how organisms migrate
    d. a reproductive behavior for attracting a mate through a ritual

22. A fruit fly vibrates its wings to serenade a potential mate. Which of the following describes the type of behavior?
    a. audible
    b. tactile
    c. electrical
    d. chemical

23. A cheetah urinates on a tree. Which of the following types of signals is the cheetah using?
    a. visual
    b. audible
    c. tactile
    d. chemical

24. A cheetah urinates on a tree. Which of the following describes the purpose of this signal?
    a. indicate dominance
    b. establish territory
    c. find food
    d. ensure reproductive success

25. Which of the following best describes the body temperature regulation for an alligator?
    a. ectotherm that maintains body temperature through metabolism
    b. ectotherm that maintains body temperature through behaviors
    c. endotherm that maintains body temperature through metabolism
    d. endotherm that maintains body temperature through behaviors

26. Which of the following best describes the changes to the trophic structure with a decrease in plant population?
    a. increase in primary and secondary consumers
    b. decrease in primary and secondary consumers
    c. decrease in secondary consumer, increase in primary consumer
    d. increase in secondary consumer, decrease in primary consumer
27. Which of the following describes the energy resource used by chemosynthetic organisms?
    a. small inorganic molecules preset in their environment
    b. organic molecules broken down by the mitochondria
    c. photons absorbed by chlorophyll in the chloroplast
    d. air movement turns hairs on organismal surface
28. Which of the following is a material that heterotrophs are unable to metabolize?
    a. carbohydrates
    b. nucleic acids
    c. lipids
    d. proteins

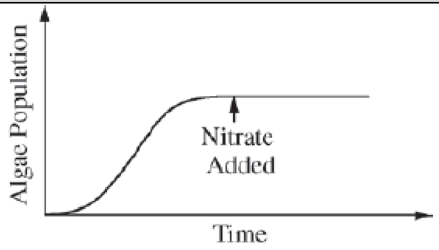
29. In a population of 100 individuals, 20 individuals are born and there are 5 deaths. What is the r value?
    Recall: r = per capita growth rate of population
    a. .05
    b. .15
    c. .20
    d. .25
30. If the population size is 100 individuals and there is a r value of 0.3, what is dN/dt?
    Recall: dN/dt = rN
    a. 10
    b. 15
    c. 30
    d. 60
31. As the population size approaches carrying capacity, dN/dt...
    a. increases steadily
    b. increases slowly
    c. decreases slowly
    d. decreases steadily
32. Which of the following describes the relationship of the mistletoe that gains resources and harms the mesquite tree that it grows on?
    a. parasitism
    b. commensalism
    c. mutualism
    d. predator/prey
33. Which of the following describes the disadvantage of little species diversity in a community?
    a. less likely to have immigration
    b. more likely to be consumed by predators
    c. more likely to have mutations
    d. less resilient to changes in the environment
34. Which of the following is an organism that is disproportionate relative to their abundance and when removed from the ecosystem causes it to collapse?
    a. dominant species
    b. invasive species
    c. keystone species
    d. primary consumer

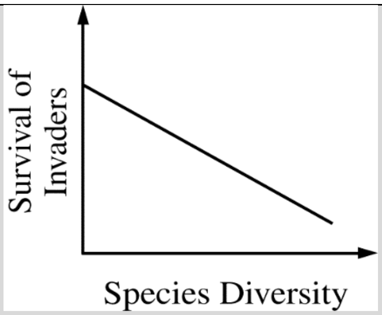
35. A group of bacteria are resistant to antibiotics. Which of the following describes HOW the bacteria became resistant?
    a. the bacterial population got changed by the antibiotic in the environment
    b. the bacterial population had random mutations making them favorable in the presence of the antibiotic
    c. the bacterial population consumed the antibiotic providing a food source
    d. the bacterial population uses the antibiotic for reproduction

36. Which of the following is NOT a reason for exponential growth of an invasive species?
    a. outcompete other organisms
    b. free of predators
    c. free of competition
    d. free of prey
37. Which process in the water cycle involves the passage of water vapor from a plant through stomata?
    a. Evaporation
    b. Condensation
    c. Precipitation
    d. Transpiration
38. Which process in the carbon cycle does not release carbon dioxide into the atmosphere?
    a. Photosynthesis
    b. Cellular Respiration
    c. Decomposition
    d. Combustion

39. Which of the following describe the correct order of events in the nitrogen cycle?
    a. Nitrogen fixation → Nitrification → Assimilation → Denitrification → Ammonification
    b. Nitrogen fixation → Nitrification → Assimilation → Ammonification → Denitrification
    c. Nitrification → Assimilation → Nitrogen Fixation → Ammonification → Denitrification
    d. Nitrification → Nitrogen fixation → Assimilation → Denitrification → Ammonification
40. Which process directly returns phosphorus to the soil in the phosphorus cycle?
    a. Producers synthesizing biological molecules
    b. Consumers eating producers
    c. Surface runoff into rivers, lakes, and oceans
    d. Weathering of rocks

Multiple Choice Key

Question	Correct Answer	Unit/Topic	Source
1	B. Environmental contamination reduces total testosterone oxido-reductase activity in females.	8.1	2012 CED #22
2	B. Elongation of seedlings in response to the lack of light	8.1	2012 CED #14
3	D. Plants generally use starch molecules for storage while animals use glycogen and fats for storage.	8.1	2012 CED #11
4	C. 	8.1	2012 CED #40
5	C. the ice blocks the light, so in years with more ice coverage, there is less photosynthesis by the phytoplankton	8.2	2013 #37
6	C. mode of internal temperature regulation	8.2	2012 CED #10
7	B. The surface fish populations would decline due to reduced populations of algae.	8.2	2013 #14
8	B. The biomass of coyotes will be dramatically reduced.	8.2	2012 CED #4
9	B. Phosphate was a limiting factor for phytoplankton in the lake.	8.3	2020 CED #4
10	C. 1,500 (mg/m^3)/year	8.3	2020 CED #5
11	A. An untreated section of the lake	8.3	2020 CED #6
12	D. The amount of energy available to consumers in the lake increased	8.2	2020 CED #7
13	C. Density of rose pollen produced (g/m^2)	8.5	2012 #2
14	A. Eventually the other trees grow taller than the oak trees and form a dense canopy that shades the understory.	8.5	2012 CED #6
15	C. *T. castaneum* with parasite at 100 days	*	2013 #10
16	B. *T. castaneum* is adversely affected by the parasite, while *T. confusum* is not.	*	2013 #11
17	D. The natural variation among populations	*	2013 #12
18	B. 10 beetles/culture dish	*	2013 #13

19	D. 	8.7	2013 #8
20	D. Building ponds in the areas of dry land to promote interbreeding between the separated populations	8.7*	2013 #24
21	B. a selfless behavior to save the population but risk yourself	8.1	Self
22	A. audible	8.1	Self
23	D. chemical	8.1	Self
24	B. establish territory	8.1	Self
25	B. ectotherm that maintains body temperature through behaviors	8.2	Self
26	B. decrease in primary and secondary consumers	8.2	Self
27	A. small inorganic molecules preset in their environment	8.2	Self
28	B. nucleic acids	8.2	Self
29	B. 0.15	8.3	Self
30	C. 30	8.3	Self
31	B. increases slowly	8.4	Self
32	A. parasitism	8.5	Self
33	D. less resilient to changes in the environment	8.6	Self
34	C. keystone species	8.6	Self
35	B. the bacterial population had random mutations making them favorable in the presence of the antibiotic	8.7	Self
36	D. free of prey	8.7	Self
37	D. Transpiration	8.2	Self
38	A. Photosynthesis	8.2	Self
39	B. Nitrogen fixation → Nitrification → Assimilation → Ammonification → Denitrification	8.2	Self
40	D. Weathering of rocks	8.2	Self

Multiple Choice Explanations

Q		Explanation:
1	A	The environmental contamination was found in the Apopka. The mean activity of Woodruff is larger than the mean activity of Apopka. This option is incorrect. Environmental contamination in Lake Apopka had a negative effect on the enzyme in females by decreasing the activity, not increasing the activity, as in Lake Woodruff, which was not contaminated. (CollegeBoard)
	B	**Using the error bars allows you to determine the statistically significant data. The error bars between the Woodruff males and Apopka males overlap so there is no difference meaning that the environmental contamination has no affect on the oxido-reductase activity in males. The error bars between the Woodruff females and Apopka females do not overlap so there is statistically significant difference. The mean value decreased showing the environmental contamination (found in the Apopka) reduces the oxido-reductase activity in females.** **This option is correct. In Lake Woodruff, the lake that is relatively pristine, females had high levels of oxido-reductase enzyme activity, but in Lake Apopka, where environmental contamination conditions were severe, the enzyme activity was low, indicating that environmental factors had an influence on the organism. (CollegeBoard)**
	C	The male data is not statistically significant since the error bars overlap. This option is incorrect. Environmental contamination in both lakes did not seem to influence the enzyme for activity for males. (CollegeBoard)
	D	The male data is not statistically significant since the error bars overlap. This option is incorrect. Environmental contamination in both lakes did not seem to influence the enzyme for activity for males (CollegeBoard)
2	A	The seedlings in the absence of light were taller than those in the presence of light so the cells were not shortened in the absence of light. This option is incorrect. Shortening of cells in response to a lack of light would result in slower growth, but this claim is not supported by the data. (CollegeBoard)
	B	**The seedlings in Dish A were covered until Day 7 while Dish B seedlings were uncovered. The dish A seedlings have a mean height of 8 mm and dish B seedlings have a mean height of 3 mm. The elongation seen was in response to the lack of light. Logically, the seedlings “think” they are deeper in the soil and are reaching for the sunlight to begin photosynthesis with their cotyledons.** **This option is correct. In response to the lack of light, the plant elongates cells in an attempt to reach light necessary for photosynthesis at the expense of leaf development. (CollegeBoard)**
	C	The seedlings in the absence of light were taller than those in the presence of light so the light did not enhance stem elongation. This option is incorrect. In the seeds that were exposed to light, the plants actually grew more slowly, so enhancement of stem elongation is not supported by the data. (CollegeBoard)
	D	This is not plausible. The chances of this happening are low that you would just happened to pick the 20 seedlings that had the “tall” genes and the 20 seedlings that had “short” genes)

		This option is incorrect because genetic differences were accounted for by using 20 seeds each from the same species. (CollegeBoard)
3	A	This does not apply to metabolic strategies. The organisms are demonstrating the processes to maintain homeostasis in cold environments. This option is incorrect despite being a correct statement. These strategies help the different organisms to survive cold periods but are not metabolic strategies for meeting their energy needs. (CollegeBoard)
	B	This does not apply to metabolic strategies. The prokaryotes do not have introns and the eukaryotes do have introns. This option is incorrect because this fact comparing bacterial and eukaryotic genomes and the presence of introns has nothing to do with these organisms meeting their energy needs by varying metabolic strategies. (CollegeBoard)
	C	This does not apply to metabolic strategies. The carnivores have different dentition than the herbivores. This option is incorrect. Metabolism is defined as the totality of an organism's chemical reactions. The type of teeth organisms have would not be considered a metabolic strategy but rather a structural strategy (CollegeBoard)
	D	**Starch is the (glucose) energy storage for plants while glycogen and fats are the (glucose) energy storage for animals. This demonstrates that plants vs animals use different strategies for energy requirements.** **This option is correct. Starch, glycogen, and fat are all molecules used for energy storage, yet plants have evolved to use starch while animals have evolved to use fat for long-term energy storage and glycogen for short-term energy storage. (CollegeBoard)**
4	A	Nucleic acids need both phosphate and nitrogen (nitrate). In the absence of phosphate, the algal would not see an increase of the algae population. This option is incorrect because the phosphate is limiting; thus, additional nutrients would have no effect. (CollegeBoard)
	B	In the absence of both nitrate and phosphate, the algal population did not decrease so it wouldn't decrease when you added the nutrient. This option is incorrect because the addition of nitrogen, an essential plant nutrient, would not decrease the algal growth (CollegeBoard)
	C	**Nucleic acids need both phosphate and nitrogen (nitrate). With the nitrate being added instead of the phosphate, the algal population will stop growing and level out.** **This option is correct because the limiting nutrient is phosphate, not nitrogen. (CollegeBoard)**
	D	In the absence of both nitrate and phosphate, the algal population did not decrease so it wouldn't decrease when you added the nutrient. This option is incorrect because adding nitrogen, an essential plant nutrient, would not increase then decrease the algal growth (CollegeBoard)
5	A	Zooplankton consume phytoplankton. The amount of sunlight does not affect zooplankton's production of food for the fish.
	B	We do not have any data to support this statement.

	C	**Primary Production is the quantitative measurement for photosynthesis. As the months with open waters increases, the primary production increases. This is logical as the photosynthetic organisms have more access to sunlight for primary production. The more sunlight, the more phytoplankton. Since the food of the zooplankton increased, the zooplankton's population increased. Since the food of codfish increased, the codfish's population increased.**
	D	Ice covering decreases the light available for photosynthesis.
6	A	The data is per gram of tissue, so it has been adjusted for the size difference. This option is incorrect because the rate of oxygen consumption is due to metabolic rates since oxygen is necessary for ATP production. Though size does affect heat gain and loss due to surface area to volume ratios, this physical trait would have the same effect in both organisms, not the opposite. (CollegeBoard)
	B	Both organisms are herbivores. This option is incorrect because both crickets and mice are chemoheterotrophs. (CollegeBoard)
	C	**Crickets are ectotherms. Their internal temperature is dependent on their environment. Mice are endotherms. Their internal temperature is dependent on metabolism. As the temperature decreases, the mice will undergo more cellular respiration to generate heat to warm the organism's bodies. As increase in cellular respiration is represented by an increase in respiration (oxygen is needed as the final electron acceptor).** **This option is correct because crickets are ectotherms. Ectotherms have very low metabolic rates, so they depend on the environment to help regulate their internal temperature. Therefore, crickets would have a higher metabolic rate at the higher temperature due to kinetics or more frequent molecular collisions. (CollegeBoard)**
	D	Both organisms undergo cellular respiration to synthesize ATP. This option is incorrect because both organisms produce ATP via aerobic cellular respiration when oxygen is not a limiting reactant. (CollegeBoard)
7	A	Nitrogen is needed for proteins and nucleic acids, so there would be a decrease in the algae population due to limiting nutrients.
	B	**There was a decrease in the whale population which led to a decrease in the nitrogen (reduction in feces deposited). This decrease in nitrogen leads to a decrease in the algae. A decrease in algae is a decrease in food for the fish. This leads to a decrease in fish population.**
	C	The whale population decreasing does not cause mutations.
	D	This is logical, but the question asks for the 'best predicts". Due to the decrease in nitrogen there is a decrease in the algae population which decreased the fish population. There is no information that states the whales are unable to forage in the upper regions of the ocean.
8	A	There is no information to allow this to be determined. This option is incorrect. The quantitative data provided in the scenario do not support this conclusion regarding changes in biomass for coyotes and hawks. (CollegeBoard)
	B	**All of the rabbits and deer are removed which is all of the food for the coyote. Due to this loss of prey, the coyote will die which reduces their (dramatically) reduces their biomass.** **This option is correct. It demonstrates an understanding of the components of a food web and interactions between all of the participants. Coyotes prey on deer and rabbits, and if developers remove them, coyotes will lose their primary source of nutrition/energy. With this loss of**

		nutrition/energy they will experience a decrease in reproductive success and therefore a significant decline in their population. (CollegeBoard)
	C	There is no information about that coyotes would out complete hawks. This option is incorrect. The data do not provide evidence to support the conclusion that with the removal of deer and rabbits the coyotes will switch to preying on voles and outcompeting hawks for the energy source. (CollegeBoard)
	D	There is no information to calculate the effect on the 50% biomass decrease. This option is incorrect. The vole population may not suffer because there is no longer competition from rabbits and deer for the grass. With the removal of rabbits, hawks will lose a source of energy. However, because hawks also prey on voles whereas coyotes do not, hawks still will have a source of energy. (CollegeBoard)
9	A	Carbon was added in the form of sucrose. Both samples got the sucrose, but only one sample demonstrated an increase in growth demonstrating that carbon was not a limiting nutrient.
	B	**There are two lines on the graph. The line with sucrose has a low amount of phytoplankton biomass but the line with sucrose and phosphate has a large amount of phytoplankton biomass. This demonstrates that phosphate is a limiting nutrient and is required for growth of the phytoplankton.**
	C	Carbon was added in the form of sucrose. Both samples got the sucrose, but only one sample demonstrated an increase in growth demonstrating that carbon was not a limiting nutrient. When phosphate was added to one group, that group showed an increase demonstrating that phosphate was a limiting nutrient.
	D	There was low growth with the sucrose only sample demonstrating there is a limiting nutrient.
10	A	You made a math error, but I can't think of what math would produce this answer to re-direct you.
	B	You made a math error, but I can't think of what math would produce this answer to re-direct you.
	C	**(1971, 1000) and (1975, 7000)** **Rate = $(y_2 - y_1) / (x_2 - x_1) = (7000 - 1000)/(1975 - 1971) = 6000/4 = 1500$**
	D	Rate involves dividing by the change in time. This answer choice is the phytoplankton biomass difference (7000 – 1000 = 6000)
11	A	**Provides a point of comparison of these two samples to determine how sucrose and phosphate affect the phytoplankton.**
	B	This helps you to determine the affect of phosphate alone, but it is still a treatment group.
	C	This allows you to compare your treatment to increase your sample size.
	D	This does not include the same constants as the environmental lake so it cannot be used as a point of comparison.
12	A	The phosphate leads to an increase in phytoplankton biomass so the biomass in the first trophic level would increase.
	B	If there is an increase in phytoplankton, there would be an increase of the consumers of phytoplankton (second trophic level).
	C	The phosphate does not provide energy nor does it assist the phytoplankton in obtaining sunlight.
	D	**The phosphate provided the nutrient for the phytoplankton to grow. The increase in phytoplankton would increase the food supply for the consumers and thus an increase in energy available to consumers.**
13	A	The sunlight although provides energy to the plant does not answer the researchers question regarding if food abundance was the cause.
	B	The temperature although could affect the plants. It does not answer the researchers question regarding if food abundance was the cause.

	C	**The rose pollen is the food resource for the thrips. This information would tell you how much rose pollen there is in how much space to ensure there is enough food for the thrips.**
	D	This tells you how much food is available from a flower, but there is no information about the number of flowers to be able to determine if the thrips didn't have enough food.
14	A	**As ecological succession continues, the trees get larger. Their height is an evolutionary advantage to obtain more sunlight. Since the trees obtain the sunlight and shade the shrubs, they are unable to compete and do not receive enough sunlight so they die.** **This option is correct. The other trees shade out the oak trees. Oak seedlings are relatively intolerant to shade. Oak trees need sunlight for photosynthesis, and although they do survive in poor sunlight, they do not proliferate enough to be the dominant plant in the forest. Some oak species need sunlight for full development (CollegeBoard)**
	B	This information cannot be obtained from the diagram. This option is incorrect for two reasons: First, the shrubs disappear in this progression, so there is no evidence that any change would enhance shrub growth. Second, oak trees do not significantly alter the pH of the soil. (CollegeBoard)
	C	If the oak trees are unable to obtain water, they will be unable to replace the shrubs. This option is incorrect because shrubs have relatively small root balls and would not out-compete an oak tree with a deep tap root. When the shrubs disappear, the success of the oak tree does not improve (CollegeBoard)
	D	If the oak trees are less favorable in the presence of environmental pollutants, they would be unable replacing the shrubs. This option is incorrect because there is no evidence in this data of environmental pollutants. Although pollutants do affect oak tree growth, oaks are not considered more sensitive to them than other trees. (CollegeBoard)
15	A	*T. confusum* with parasite at 500 days = 10 beetles
	B	*T. confusum* without parasite at 300 days = 15 beetles
	C	***T. castaneum* with parasite at 100 days = 30 beetles**
	D	*T. castaneum* with parasite at 600 days = 10 beetles
16	A	In the graph of *T. confusum* the two lines are very close demonstrating that the parasite had little to no effect on the number of beetles.
	B	**In the graph of *T. confusum* the two lines are very close demonstrating that the parasite had little to no effect on the number of beetles. In the graph of *T. castaneum,* the without parasite line was higher than the with parasite line. This shows that the parasite has a negative effect on the number of beetles.**
	C	In the graph of *T. confusum* the two lines are very close demonstrating that the parasite had little to no effect on the number of beetles.
	D	In the graph of *T. castaneum,* the without parasite line was higher than the with parasite line. This shows that the parasite has a negative effect on the number of beetles.
17	A	They were tested in the same environment with the only difference of whether there is a parasite present.
	B	Figure 1 shows very little difference between the presence of parasite and the absence of the parasite.
	C	If there was competition, you would see a decrease in both populations.
	D	**There will be a natural variation in the population. This is why the statistical analysis is important for data interpretation.**
	A	It is at 10 beetles/culture dish, and it will stabilize not drop to 5.

18	B	**It is already at 10 beetles/culture dish.**
	C	It is at 10 beetles/culture dish, and it will stabilize not increase to 20.
	D	It is at 10 beetles/culture dish, and it will stabilize not increase to 25.
19	A	This graph shows there is no difference in survival of invaders as the species diversity increases.
	B	This graph shows an initial decrease in survival of invaders as species diversity increased, but then the graph increases.
	C	This shows as the species diversity increases, the survival of invaders also increases. This does not show that it will resist change.
	D	**As the species diversity increases, the survival of invaders decreases. The community with a high diversity will inhibit change (hence the decreased survivability of invaders)**
20	A	Cloning would provide genetically identical individuals. This does not increase genetic diversity.
	B	Reducing the population size could decrease the genetic diversity if a trait/allele is removed.
	C	Decreasing the water inhibits the amphibian movement which restricts gene flow (which does not allow the populations to increase genetic diversity).
	D	**The amphibians lack genetic diversity. In order to increase the genetic diversity, there needs to be an increase in gene flow. There is wide areas of dry land between the ponds which would inhibit the mating of amphibians from different ponds. If humans build ponds between them, this would increase the amphibians mating and provide the genetic diversity needed.**
21	A	This is a territorial behavior
	B	**Altruism refers to a selfless behavior that increases the inclusive fitness of a group.**
	C	I was just coming up with some alternative answers that sounded good. You are still amazing even if you selected this answer.
	D	This describes behavioral isolation.
22	A	**Audible are sounds**
	B	Tactile is touch
	C	Electrical is electricity or ions
	D	Chemical is chemical messengers
23	A	Visual is something that is “seen”
	B	Audible are sounds
	C	Tactile is touch
	D	**Chemical is chemical messengers**
24	A	To indicate dominance would traditionally be aggressive or agnostic behaviors
	B	**There are chemicals in the urine which allow for the cheetah to mark its territory**
	C	How does peeing on a tree help the cheetah to get food?!?
	D	How does peeing on a tree help the cheetah to increase reproductive success?!?
25	A	Organisms use energy to maintain organization, grow, and reproduce—(a) Organisms use different strategies to regulate body temperature and metabolism. i. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures. ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals (ENE-1.M.1)
	B	**Organisms use energy to maintain organization, grow, and reproduce—(a) Organisms use different strategies to regulate body temperature and metabolism. ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals (ENE-1.M.1) Alligators are ectotherms.**
	C	Organisms use energy to maintain organization, grow, and reproduce—(a) Organisms use different strategies to regulate body temperature and metabolism. i. Endotherms use thermal energy generated

		by metabolism to maintain homeostatic body temperatures. (ENE-1.M.1) Alligators are ectotherms instead of endotherms.
	D	Organisms use energy to maintain organization, grow, and reproduce—(a) Organisms use different strategies to regulate body temperature and metabolism. i. Endotherms use thermal energy generated by metabolism to maintain homeostatic body temperatures. ii. Ectotherms lack efficient internal mechanisms for maintaining body temperature, though they may regulate their temperature behaviorally by moving into the sun or shade or by aggregating with other individuals (ENE-1.M.1)
26	A	If there is a decrease in the producers, there will be less food for the primary and secondary consumes which would decrease their populations.
	B	**Changes in energy availability can result in disruptions to an ecosystem—(a) A change in energy resources such as sunlight can affect the number and size of the trophic levels. (b) A change in the producer level can affect the number and size of other trophic levels (ENE.1.N.2)**
	C	If there is a decrease in the producers, there will be less food for the primary consumers which decreases their population leading to less food for the secondary consumes which would decrease their population.
	D	If there is a decrease in the producers, there will be less food for the primary consumers which decreases their population leading to less food for the secondary consumes which would decrease their population.
27	A	**Autotrophs capture energy from physical or chemical sources in the environment—(b) Chemosynthetic organisms capture energy from small inorganic molecules present in their environment, and this process can occur in the absence of oxygen. (ENE-1.O.1)**
	B	Mitochondria uses organic molecules as a part of cellular respiration
	C	Phototrophs use light energy (photons) absorbed by chlorophyll in a chloroplast during photosynthesis
	D	Did it sound good to you? I was just trying to come up another answer choice.
28	A	Heterotrophs capture energy present in carbon compounds produced by other organisms. (a) Heterotrophs may metabolize carbohydrates, lipids, and proteins as sources of energy by hydrolysis. (ENE-1. O.2)
	B	**Nucleic acids are not broken down for metabolism.**
	C	Heterotrophs capture energy present in carbon compounds produced by other organisms. (a) Heterotrophs may metabolize carbohydrates, lipids, and proteins as sources of energy by hydrolysis. (ENE-1. O.2)
	D	Heterotrophs capture energy present in carbon compounds produced by other organisms. (a) Heterotrophs may metabolize carbohydrates, lipids, and proteins as sources of energy by hydrolysis. (ENE-1. O.2)
29	A	This is just the death rate of 5/100 = 0.05
	B	**B = 20/100 = 0.2 D = 5/100 = 0.05 r = B – D = 0.2 – 0.05 = 0.15**
	C	This is just the birth rate of 20/100 – 0.20
	D	Did you add B and D when you were supposed to subtract?
30	A	This number looked good with the other numbers.
	B	I calculated half of the correct answer (15)
	C	**dN/dt = rN = (0.3)(100) = 30**
	D	I calculated double the correct answer (D)
31	A	The rate will not be as great since the environment is approaching its maximum occupancy.
	B	**As N approaches K, dN/dt approaches 0 because (K – N)/K approaches 0.**
	C	K – N does not become a negative number so dN/dt remains with a positive slope
	D	K – N does not become a negative number so dN/dt remains with a positive slope
32	A	**In parasitism, the host is negatively impacted and parasite is positively affected**
	B	In commensalism, one is benefited while the other has no effect.
	C	In mutualism, both organisms are benefited.
	D	In predator/prey, the predator is benefited and the prey is harmed.

33	A	If species diversity is low, there would be an increase in gene flow to bring the new alleles to the population.
	B	Species diversity has no effect on predator/prey relatioships
	C	Species diversity has no effect on the mutations.
	D	**Natural and artificial ecosystems with fewer component parts and with little diversity among the parts are often less resilient to changes in the environment.** (SYI-3.F.1)
34	A	The dominant species if the most abundant species in the population.
	B	Invasive species were introduced to the population. They have no natural predators.
	C	**The effects of keystone species on the ecosystem are disproportionate relative to their abundance in the ecosystem, and when they are removed from the ecosystem, the ecosystem often collapses** (SYI-3.G.2).
	D	The primary consumer is consumes the plant materials from the ecosystem.
35	A	This is a COMMON error among students. The antibiotic does not cause the mutations that allowed for natural selection.
	B	**This describes natural selection. The bacteria have pre-existing mutations that allowed them to be able to survive in the presence.**
	C	The bacteria would be unable to consume the antibiotic unless they were resistant and were not effected by a little light.
	D	The antibiotic restricts growth.
36	A	The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete other organisms for resources. (SYI-2.A.1)
	B	The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete other organisms for resources. (SYI-2.A.1)
	C	The intentional or unintentional introduction of an invasive species can allow the species to exploit a new niche free of predators or competitors or to outcompete other organisms for resources. (SYI-2.A.1)
	D	**If there are no prey, then there would be a decrease in the population size.**
37	A	Although evaporation is the process of liquid water transforming into water vapor and rising into the atmosphere. This is a process that occurs with non-living surface such as oceans, lakes, rivers, and moist soil. Since the question distinctly mentions the release of water from a plant, this would be incorrect.
	B	Condensation is the process of water vapor transforming into liquid water.
	C	Precipitation refers liquid and solid water particles falling from clouds to reach the ground.
	D	**Transpiration is a biological process in which plants release water vapor into the atmosphere, primarily through tiny pores on their leaves called stomata. While it involves the change of water from liquid to gas, it is distinct because it occurs within living plant tissues. Water absorbed by the roots travels up through the plant's vascular system, the xylem, to the leaves.** **Once in the leaves, water moves into air spaces and then diffuses out through the stomata as water vapor. These stomata are regulated by specialized guard cells that control their opening and closing, allowing plants to manage water loss in response to environmental conditions. Although plants use water for growth and metabolism, a significant portion is released through transpiration.** (What Is the Difference Between Evaporation and Transpiration? - Biology Insights)
38	A	Photosynthesis is a process that absorbs carbon dioxide from the atmosphere to incorporate it into biological molecules.
	B	Cellular respiration is a process that releases carbon dioxide to the atmosphere from the breakdown of biological molecules.

	C	Decomposition is a process that transforms dead plants, animals, and organic materials into simpler substances. When this process occurs, carbon stored in plants and animal tissue is released back into the atmosphere as carbon dioxide.
	D	Combustion refers to the process of burning fossil fuels and biomass. In this process, fossil fuels and biomass react with oxygen to produce carbon dioxide and water vapor thus increasing the concentration of carbon dioxide.
39	A	The last two are out of order: Ammonification: Decomposers convert organic nitrogen back into ammonia, which can be used by plants. Denitrification: Bacteria convert nitrates back into nitrogen gas (N_2), returning it to the atmosphere.
	B	The order of movement of nitrogen in the nitrogen cycle is: Nitrogen Fixation: Atmospheric nitrogen (N_2) is converted into ammonia (NH_3) by certain bacteria and blue-green algae. This process is crucial for making nitrogen available for plants. Nitrification: Ammonia is converted into nitrites (NO_2^-) and then into nitrates (NO_3^-) by soil bacteria. Assimilation: Plants absorb nitrates and convert them into organic nitrogen compounds. Ammonification: Decomposers convert organic nitrogen back into ammonia, which can be used by plants. Denitrification: Bacteria convert nitrates back into nitrogen gas (N_2), returning it to the atmosphere.
	C	The first three are out of order: Nitrogen Fixation: Atmospheric nitrogen (N_2) is converted into ammonia (NH_3) by certain bacteria and blue-green algae. This process is crucial for making nitrogen available for plants. Nitrification: Ammonia is converted into nitrites (NO_2^-) and then into nitrates (NO_3^-) by soil bacteria. Assimilation: Plants absorb nitrates and convert them into organic nitrogen compounds.
	D	The first three are out of order: Nitrogen Fixation: Atmospheric nitrogen (N_2) is converted into ammonia (NH_3) by certain bacteria and blue-green algae. This process is crucial for making nitrogen available for plants. Nitrification: Ammonia is converted into nitrites (NO_2^-) and then into nitrates (NO_3^-) by soil bacteria. Assimilation: Plants absorb nitrates and convert them into organic nitrogen compounds.
40	A	The process of synthesizing biological molecules will be storing the phosphorus in organisms.
	B	The process of consumers eating producers transfer the phosphate to the animals.
	C	Surface runoff into river, lakes, and oceans moves the phosphate into the body of water to be a part of marine sediments.
	D	Weathering of rocks involves deterioration of rocks and returns the phosphate back into the soil.

Free Response Practice

2025 #3

Buffelgrass, an invasive grass species in southwestern desert ecosystems, is threatening the saguaro cactus, a keystone species in these ecosystems. Buffelgrass is drought-tolerant and can survive wildfires. However, the dry buffelgrass also acts as fuel for wildfires, causing the fires to be more severe. Older saguaro cacti can survive wildfires; however, many of the young cacti cannot.

Scientists conducted an experiment to determine whether they could control the abundance of the buffelgrass population. The scientists identified several native grass species that, when grown with buffelgrass, might reduce the abundance of buffelgrass. They grew buffelgrass in the presence of several different native grass species in greenhouses, in either nondrought (watered every 3 days) or drought (watered every 9 days) conditions. After twelve weeks, they measured the height and dry weight of the buffelgrass in each treatment group.

(a) **Describe** the effect that removing a keystone species will have on an ecosystem.
(b) **Identify** a control group the scientists should include in their experiment.
(c) **State** the null hypothesis of the experiment in which buffelgrass is grown in the presence of native grass species.
(d) Scientists have found that the population growth rates of native grasses are much slower than the population growth rate of buffelgrass following a wildfire. The scientists claim that wildfires will therefore increase the abundance of buffelgrass plants in the ecosystem. Based on the information given, **justify** the scientists' claim.

2024 #4

The common wild oat is native to regions of Europe and Asia but is an invasive species in central California grasslands. In California, the common wild oat has almost completely replaced some species of native bunchgrass. Researchers found that aphids, a type of small insect that often carries plant viruses, have a much higher reproductive rate in grasslands that include the common wild oat than in grasslands composed of only native bunchgrass species. Additionally, the viruses carried by the aphids appear to affect only the native bunchgrasses and not the common wild oat. Native bunchgrasses infected by the virus have much higher death rates than do native bunchgrasses that are not infected.

(a) **Describe** the change in the resilience of an ecosystem when there is a decrease in the number of species.

(b) **Explain** how the addition of the common wild oat affects the number of native bunchgrass plants that can be supported by the California grasslands ecosystem.

(c) Researchers suggest adding ladybugs, predators of aphids, to the California grasslands. **Predict** the effect of adding ladybugs on the abundance of the native bunchgrass population.

(d) **Justify** your prediction in part (c).

2023 #3

Sand lances of the genus *Ammodytes* are small fish that function as keystone organisms in several coastal ecosystems. These sand lances are prey fish that support organisms at higher trophic levels. Scientists performed experiments to examine how sand lance populations are likely to be affected by the rising temperatures and CO_2 levels associated with climate change.

Sand lance embryos typically develop and mature into adult fish at low temperatures (approximately 5°C) and stable, low CO_2 levels (approximately 400 µatm). Over the course of two years, the scientists measured the survival rate of sand lance embryos allowed to develop and mature in a laboratory at three different temperatures, 5°C, 7°C, and 10°C, with the level of CO_2 maintained at 400 µatm, 1,000 µatm, and 2,100 µatm for each temperature.

(a) **Describe** the effect of increased biodiversity on the resilience of an ecosystem in a changing environment.

(b) Justify the scientists' selecting 5°C as the lowest temperature and 400 µatm as the lowest CO_2 level in their study of sand lance embryo survival.

(c) **State** a null hypothesis for the experiment.

(d) The scientists claim that a reduction in the population size of the *Ammodytes* sand lances will affect the stability of the entire coastal ecosystem. Provide reasoning to support the scientists' claim.

2022 #5

The following models represent all the interacting species in two different communities with some of the same species and feeding relationships. These models assume that both communities have the same initial biomass. The models can be used to understand the effects of human activities on the communities.

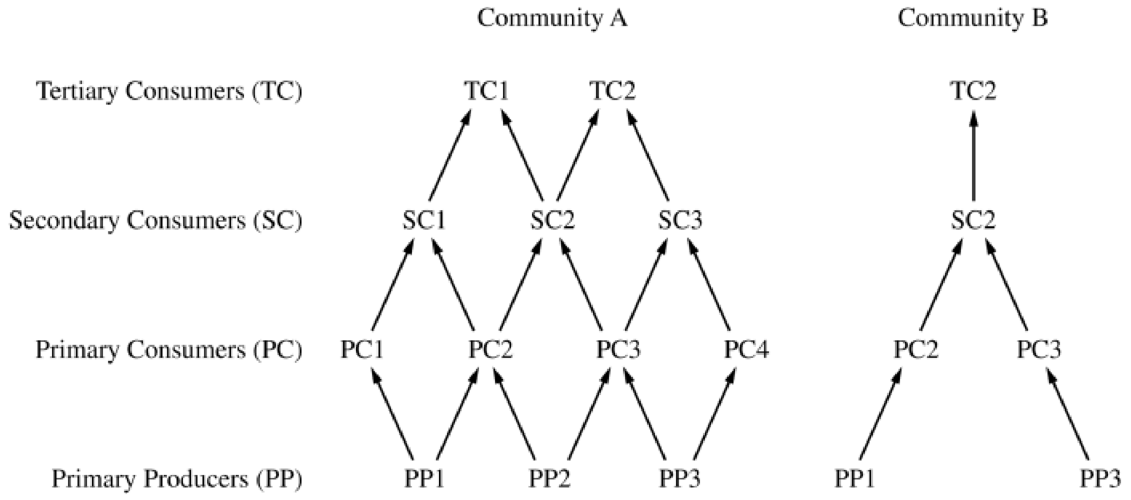

Community A
Community B
Tertiary Consumers (TC)
Secondary Consumers (SC)
Primary Consumers (PC)
Primary Producers (PP)
TC1
TC2
SC1
SC2
SC3
PC1
PC2
PC3
PC4
PP1
PP2
PP3
TC2
SC2
PC2
PC3
PP1
PP3

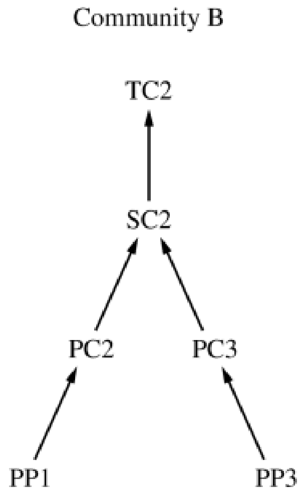
Figure 1. Models of two different communities with some of the same species

(a) **Describe** a characteristic of a community that makes a species invasive in that community but not invasive in a different community.

(b) **Explain** why removing species PP1 will have a greater effect on community B than on community A.

(c) An invasive species (INV) that eats individuals of species SC2 is introduced into community B. Using the template in the space provided for your response, for community B, indicate the feeding relationship for this invasive species by correctly placing **INV** to represent the invasive species and an **arrow** to represent the feeding relationship within community B.

(d) **Explain** how human activities that add toxins to the soil could change a community with many species at each trophic level, such as community A, into a community with few species at each trophic level, such as community B.



2021 #5

Annual plants complete their life cycle, including germination, seed production, and death, within one year. *Ambrosia trifida* (giant ragweed) is an annual plant that readily colonizes any land that has had a disturbance such as plowing. The plant is considered an invasive species in regions outside of its native range. In a particular region, the seeds of *A. trifida* germinate from early March through the end of the summer, while the seeds of other annual plants require warmer soil temperatures and thus germinate from late April through the end of the summer.

Researchers studied the influence of *A. trifida* on the biodiversity of other annual plant species that grow in the same field. In early spring, the researchers marked off identical plots of land in a field that had been plowed the previous fall and not replanted with new crops. All plants that grew on one half of the plots were left untouched (Figure 1A), while all germinating *A. trifida* seedlings were removed from the other half of the plots throughout the spring and summer (Figure 1B). In late summer, the researchers counted and identified all plants that grew in the plots. The distribution of plants is represented by the symbols in Figure 1A and 1B.

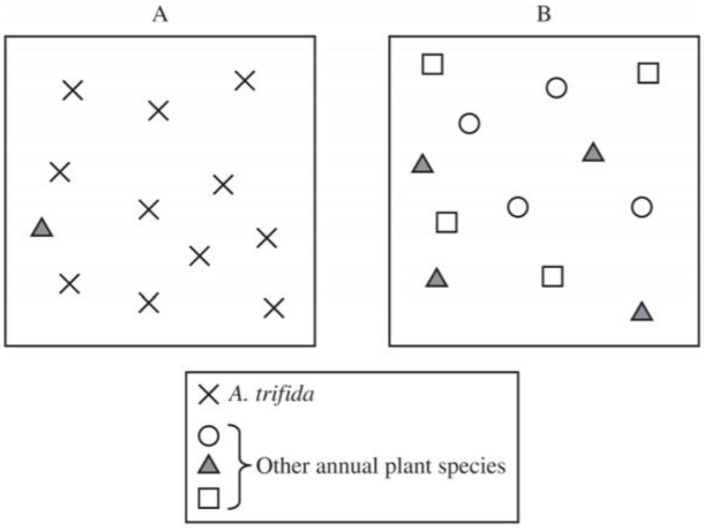


Figure 1. Representations of plant identity and distribution in experimental plots in late summer. Each box represents one typical experimental plot, and each symbol represents 10 individual plants.

(a) **Describe** a cause of logistic growth of the ragweed population.

(b) Based on the representation in Figure 1, **explain** why the scientists claim that plot B would be more resilient than plot A in response to a sudden environmental change.

(c) In a third group of plots, the researchers removed all seedlings of all plants that germinated before June 1. All plants that germinated after June 1 were left untouched. Using the template in the space provided for your response and the symbols shown in Figure 1, represent the expected plant species that would be found in this third group of plots three months later. **Draw** no more than 12 symbols. Assume all other environmental conditions are the same as for the initial study described.

(d) **Explain** how an invasive species such as ragweed affects ecosystem biodiversity, as illustrated in Figure 1.

2019 #1

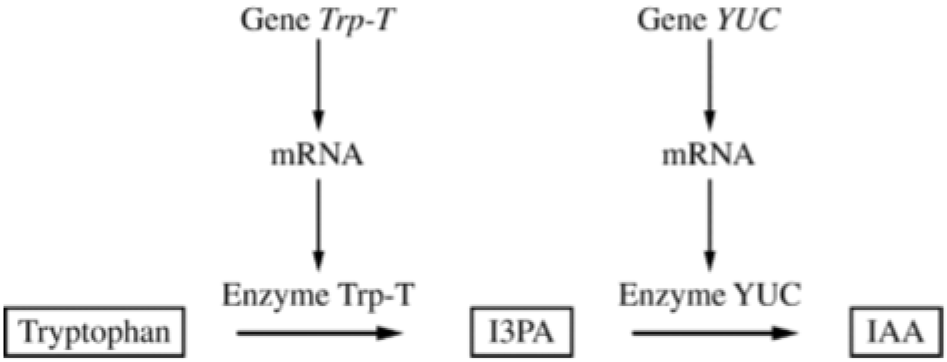


Figure 1. Model of two-step enzymatic plant pathway for synthesis of IAA from tryptophan

Auxins are plant hormones that coordinate several aspects of root growth and development. Indole-3-acetic acid (IAA) is an auxin that is usually synthesized from the amino acid tryptophan (Figure 1). Gene Trp-T encodes an enzyme that converts tryptophan to indole-3-pyruvic acid (I3PA), which is then converted to IAA by an enzyme encoded by the gene YUC.

(a) **Circle** ONE arrow that represents transcription on the template pathway. **Identify** the molecule that would be absent if enzyme YUC is nonfunctional.

(b) **Predict** how the deletion of one base pair in the fourth codon of the coding region of gene Trp-T would most likely affect the production of IAA. **Justify** your prediction.

(c) **Explain** one feedback mechanism by which a cell could prevent production of too much IAA without limiting I3PA production.

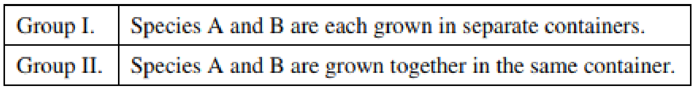
(d) Rhizobacteria are a group of bacteria that live in nodules on plant roots. Rhizobacteria can produce IAA and convert atmospheric nitrogen into forms that can be used by plants. Plants release carbon-containing molecules into the nodules. Based on this information, **identify** the most likely ecological relationship between plants and rhizobacteria. **Describe** ONE advantage to the bacteria of producing IAA.

(e) A researcher removed a plant nodule and identified several "cheater" rhizobacteria that do not produce IAA or fix nitrogen. **Describe** the evolutionary advantage of being a bacterial cheater in a population composed predominantly of non-cheater bacteria. Plants can adjust the amount of carbon-containing molecules released into nodules in response to the amount of nitrogen fixed in the nodule. **Predict** the change in the bacterial population that would cause the plant to reduce the amount of carbon-containing molecules provided to the nodule.

2019 #2

A student studying two different aquatic, plant-eating, unicellular protist species (species A and B) designed an experiment to investigate the ecological relationship between the two species (Table 1).

TABLE 1. EXPERIMENTAL TREATMENT GROUPS



Group I.	Species A and B are each grown in separate containers.
Group II.	Species A and B are grown together in the same container.

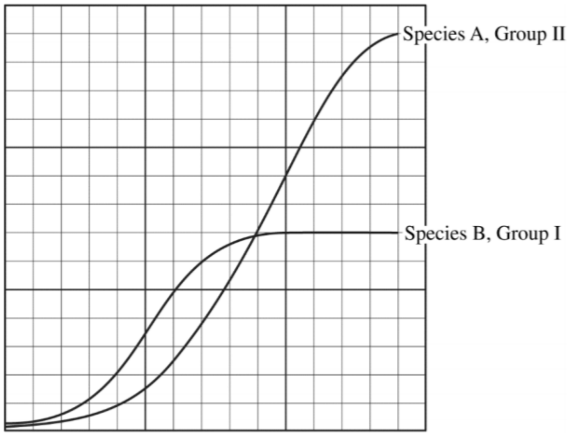
In treatment group I, the student placed 10 individuals of species A into a container with liquid growth medium and 10 individuals of species B into a separate container with an equal amount of the same liquid growth medium. In treatment group II, the student placed 5 individuals of each species into a single container with the liquid growth medium. The student then maintained the containers under the same environmental conditions and recorded the number of individuals in each population at various time points. The results are shown in Table 2.

TABLE 2. NUMBER OF INDIVIDUALS IN EACH PROTIST POPULATION IN BOTH TREATMENT GROUPS

	Group I. Grown Separately		Group II. Grown Together	
Time (h)	Species A	Species B	Species A	Species B
0	10	10	5	5
10	100	50	45	20
20	400	200	100	50
30	1100	500	250	25
40	1400	650	525	20
50	1500	700	900	10
60	1500	700	1250	0
70	1500	700	1400	0

(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded columns).

(b) As shown in the table, the student established treatment group II with 5 individuals of each species. **Provide reasoning** for the reduced initial population sizes.



(c) The student claims that species A and B compete for the same food source. **Provide TWO pieces of evidence** from the data that support the student's claim.

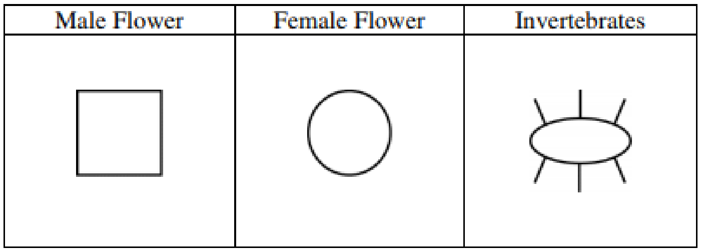
(d) **Predict** TWO factors that will most likely limit the population growth of species A in treatment group I.

(e) Many protists contain an organelle called a contractile vacuole that pumps water out of the cell. The student repeated the experiment using a growth medium with a lower solute concentration. **Predict** how the activity of the contractile vacuole will change under the new experimental conditions. **Justify** your prediction.

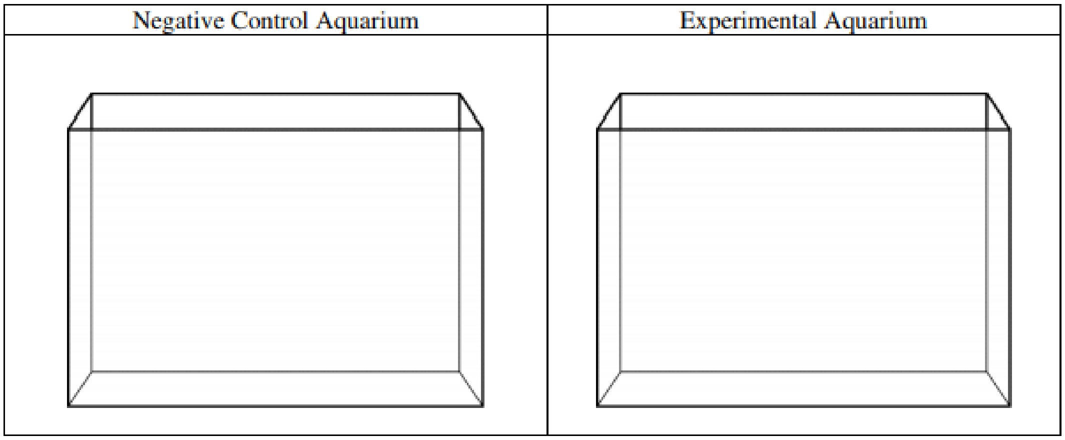
2018 #3

Seagrasses are aquatic plants that reproduce sexually. Male seagrass flowers produce sticky pollen that is carried by circulating water to female flowers, resulting in fertilization. A researcher claims that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water. To investigate this claim, the researcher set up aquariums to model the possible interaction between the invertebrates and seagrasses.

(a) Use the symbols below and the template aquariums to demonstrate the experimental design for testing the researcher's claim that mobile aquatic invertebrates can pollinate seagrass in the absence of circulating water. **Draw** the appropriate symbols in the negative control aquarium AND the experimental aquarium. Do not use an symbol more than once in the same aquarium.



(b) **Identify** the dependent variable in the experiment. **Predict** the experimental results that would support the researcher's claim that mobile aquatic invertebrates can also transfer pollen from male to female flowers in the absence of circulating water.



2018 #5

Some birds, including great spotted cuckoos, lay their eggs in the nests of other birds, such as reed warblers. The warbler parents raise the unrelated chicks and provide them with food that would otherwise be given to their biological offspring. A researcher conducted an investigation to determine the type of relationship between warblers and cuckoos in an environment without predators. The researcher found that nests containing only warblers were more likely to be successful than nests containing warblers and cuckoos (data not shown). A successful nest is defined as a nest where at least one chick becomes an adult warbler.

In some geographic areas, several species of nest predators are present. Researchers have found that cuckoo chicks, while in the nest, produce a smelly substance that deters nest predators. The substance does not remain in the nest if cuckoo chicks are removed. Figure 1 shows the probability that nest containing only warblers or containing both warblers and cuckoos will be successful in an environment with predators. In a follow-up experiment, the researchers added cuckoos to a nest that contained only warblers (group 1) and removed from a nest containing warblers and cuckoos (group 2).

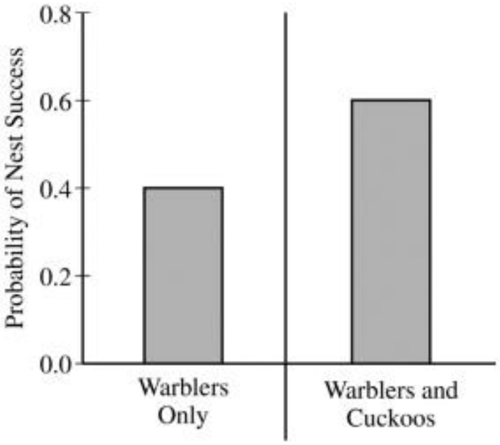


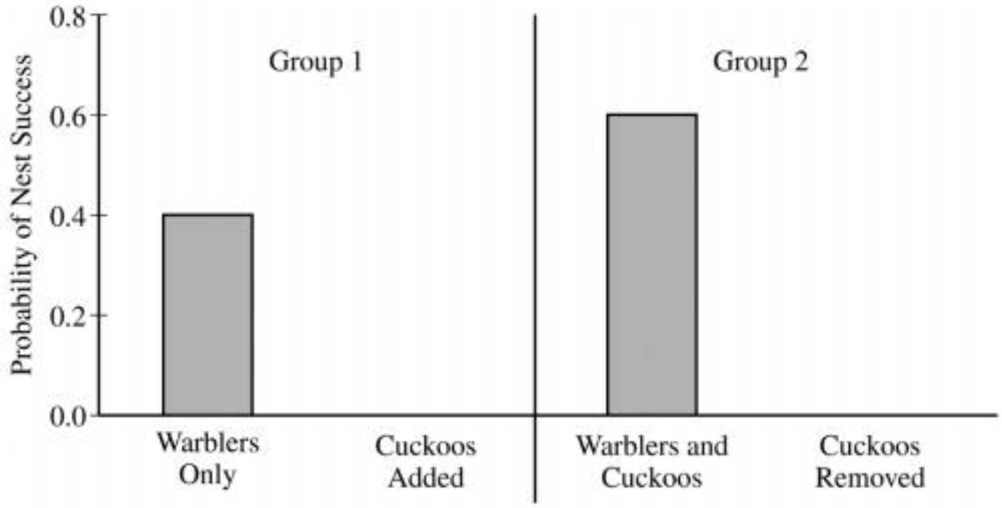
Figure 1. Probability of nest success in an environment with predators

(a) **Describe** the symbiotic relationship that exists between the cuckoo and warbler in an environment without predators.

(b) On the template provided, **draw** bars in the appropriate locations to predict the relative probability of success for the nest in the presence of predators where:

* the cuckoos were added to the nest containing only warblers (group 1)
* the cuckoos were removed from the nest containing warblers and cuckoos (group 2)

(c) **Identify** the symbiotic relationship that exists between the cuckoo and the warbler in the presence of predators.



2018 #7

In the tongue sole fish (*Cynoglossis semilaevis*), sex is determined by a combination of genetics and environmental temperature. Genetically male fish have two Z chromosomes (ZZ), and genetically female fish have one Z chromosome and one W chromosome (ZW). When fish are raised at 22°C, ZZ fish develop into phenotypic males and ZW fish develop into phenotypic females. However, when fish are raised at 28°C, the Z chromosome is modified (denoted as Z*). Z*W individuals develop as phenotypic males that are fertile and can pass on the Z* chromosome to their offspring even when the offspring are raised at 22°C. A cross between a ZW female and a Z*Z male is shown in the Punnett square below.

	Z	W
Z*	Z* Z	Z* W
Z	Z Z	Z W

(a) **Predict** the percent of phenotypic males among the F_1 offspring of the cross shown in the Punnett square if the offspring are raised at 22°C.

(b) At least one Z or Z* chromosome is necessary for survival of the fish. A researcher crossed two fish and observed a 2:1 ratio of males to females among the offspring. Based on the information, **identify** the genotype of the male parent in the cross. **Describe** ONE fitness cost to the female of mating with this particular male.

2017 #1

In flowering plants, pollination is a process that leads to the fertilization of an egg and the production of seeds. Some flowers attract pollinators, such as bees, using visual and chemical cues. When a bee visits a flower, in addition to transferring pollen, the bee can take nectar from the flower and use it to make honey for the colony.

Nectar contains sugar, but certain plants also produce caffeine in the nectar. Caffeine is a bitter-tasting compound that can be toxic to insects at high concentrations. To investigate the role of caffeine in nectar, a group of researchers studied the effect of 0.1 mM caffeine on bee behavior. The results of an experiment to test the effect of caffeine on bees' memory of a nectar source are shown in Table 1.

TABLE 1. EFFECT OF 0.1 mM CAFFEINE ON MEMORY IN BEES

Treatment	Memory (average probability of revisiting a nectar source $\pm 2\text{SE}_{\bar{x}}$)	
	10 Minutes	24 Hours
Control	0.72 ± 0.09	0.41 ± 0.07
Caffeine	0.83 ± 0.07	0.78 ± 0.08

(a) On the axes provided, **construct** an appropriately labeled graph to illustrate the effect of caffeine on the probability of bees revisiting a nectar source (memory).

(b) Based on the results, **describe** the effect of caffeine on each of the following:
(i) Short-term (10 minute) memory of a nectar source
(ii) Long-term (24 hour) memory of a nectar source

(c) **Design an experiment** using artificial flowers to investigate potential negative effects of increasing caffeine concentrations in nectar on the number of floral visits by bees. **Identify** the null hypothesis, an appropriate control treatment, and the predicted results that could be used to reject the null hypothesis.

(d) Researchers found that nectar with caffeine tends to have a lower sugar content than nectar without caffeine. Plants use less energy to produce the caffeine in nectar than they do to produce the sugar in nectar. **Propose ONE benefit** to plants that produce nectar with caffeine and a lower sugar content. **Propose ONE cost** to bees that visit the flowers of plants that produce nectar with caffeine and a lower sugar content.

2017 #2

Fires frequently occur in some ecosystems and can destroy all above-ground vegetation. Many species of plants in these ecosystems respond to compounds in smoke that regulate seed germination after a major fire. Karrikins (KAR) and trimethylbutenolides (TMB) are water-soluble compounds found in smoke that are deposited in the soil as a result of a fire. KAR and TMB bind to receptor proteins in a seed. In a study on the effects of smoke on seeds, researchers recorded the timing and percent of seed germination in the presence of various combinations of KAR and TMB. The results are shown in Figure 1.

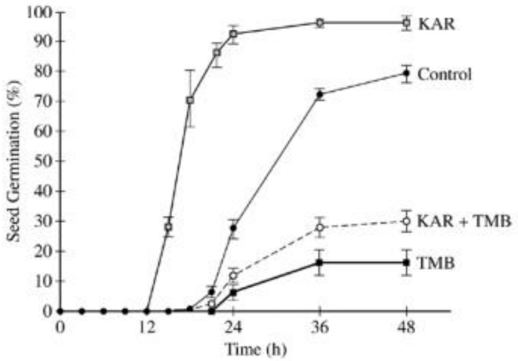
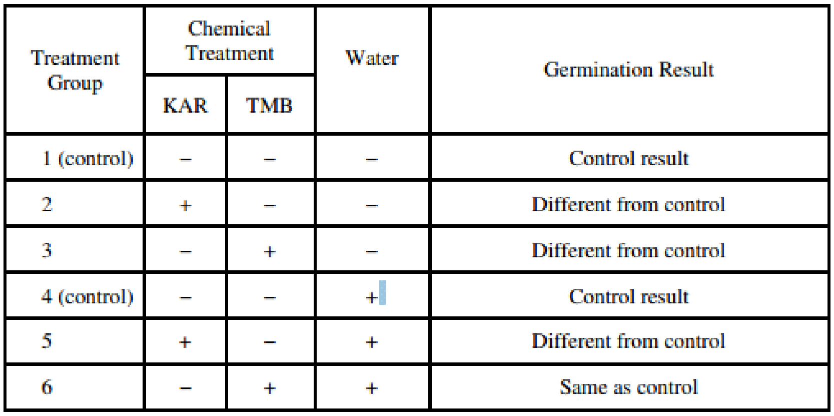


Figure 1. The effect of karrikins (KAR) and trimethylbutenolides (TMB) on seed germination in *Lactuca* plants. Error bars represent $\pm 2SE_{\bar{X}}$.

In a second investigation into the effect of available water on seed germination after a fire, researchers treated seeds with KAR or TMB. The treated seeds were then divided into two treatment groups. One group received a water rinse and the other group received no water rinse. The seeds were then incubated along with a group of control seeds that were not treated. The results are shown in the table.

EFFECT OF CHEMICAL TREATMENT AND WATER RINSE ON GERMINATION



Treatment Group	Chemical Treatment		Water	Germination Result
	KAR	TMB		
1 (control)	–	–	–	Control result
2	+	–	–	Different from control
3	–	+	–	Different from control
4 (control)	–	–	+	Control result
5	+	–	+	Different from control
6	–	+	+	Same as control

(a) The researchers made the following claims about the effect of KAR and the effect of TMB on seed germination relative to the control treatment.

- KAR alone affects the timing of seed germination
- KAR alone affects the percentage of seeds that germinate
- TMB alone affects the timing of seed germination
- TMB alone affects the percentage of seeds that germinate

Provide support using data from Figure 1 for each of the researchers' claims.

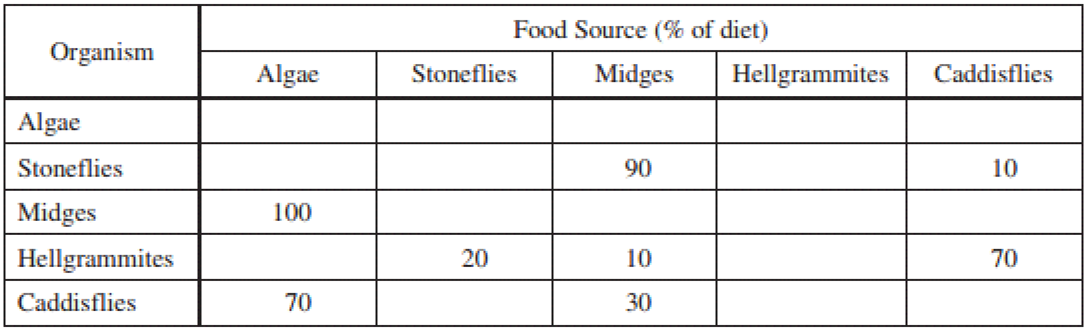
(b) **Make a claim** about the effect of rinsing on the binding of KAR to the receptor in the seed and about the effect of rinsing on the binding of TMB to the receptor in the seed. Identify the appropriate treatment groups and results from the table that, when compared with the controls, **provide support** for each claim.

(c) There is intense competition by plants to successfully colonize areas that have been recently cleared by a fire. **Describe** ONE advantage of KAR regulation and ONE advantage of TMB regulation to plants that live in an ecosystem with regular fires.

2017 #4

The table below shows how much each organism in an aquatic ecosystem relies on various food sources. The rows represent the organisms in the ecosystem, and the columns represent the food source. The percentages indicate the proportional dietary composition of each organism. High percentages indicate strong dependence of an organism on a food source.

DIETARY COMPOSITION OF ORGANISMS IN AN AQUATIC ECOSYSTEM

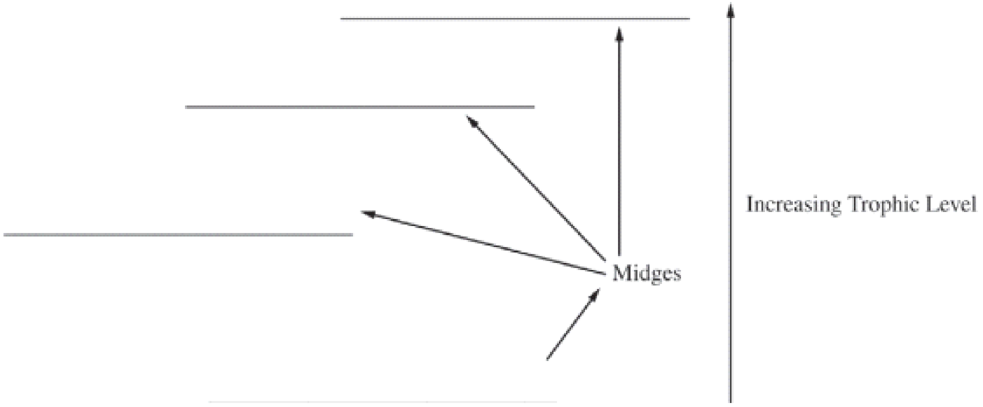


Organism	Food Source (% of diet)				
	Algae	Stoneflies	Midges	Hellgrammites	Caddisflies
Algae					
Stoneflies			90		10
Midges	100				
Hellgrammites		20	10		70
Caddisflies	70		30		

Justification (1 point)

- Stoneflies have a higher dependence on the midges than do the hellgrammites and caddisflies.
- Midges are 90 percent of the stonefly diet, while 30 percent of the caddisfly and 10 percent of the hellgrammite diet are midges.

organism names on the appropriate lines AND draw the arrows necessary to indicate the energy flow between organisms in the ecosystem.



2016 #2

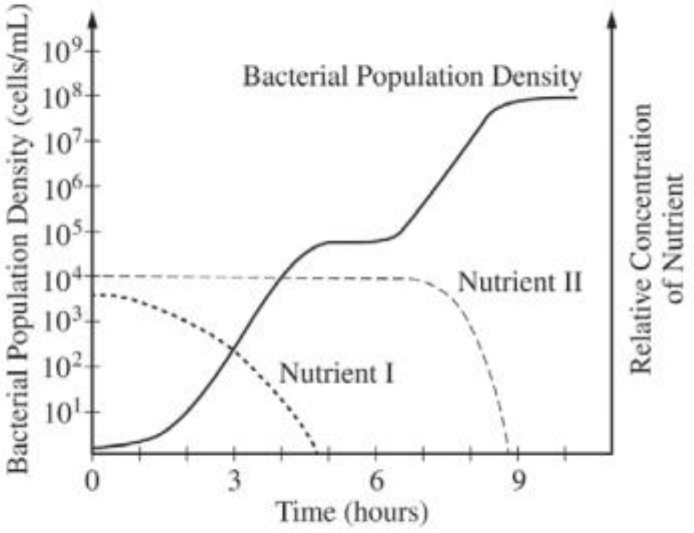


Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)

Bacteria can be cultured in media with a carefully controlled nutrient composition. The graph above shows the growth of a bacterial population in a medium with limiting amounts of two nutrients, I and II.

(a) **Estimate** the maximum population density in $\frac{cells}{mL}$ for the culture. Using the data, **describe** what prevents further growth of the bacterial population in the culture.

(b) Using the data, **calculate** the growth rate in $\frac{cells}{mL x hour}$ of the bacterial population between hours 2 and 4.

(c) **Identify** the preferred nutrient source of the bacteria in the culture over the course of the experiment. Use the graph to **justify** your response. **Propose** ONE advantage of the nutrient preference for an individual bacterium.
(d) **Describe** how nutrient I most likely regulates the genes for metabolism of nutrient I and the genes for metabolism of nutrient II. **Provide** TWO reasons that the population does not grow between hours 5 and 6.

2016 #3

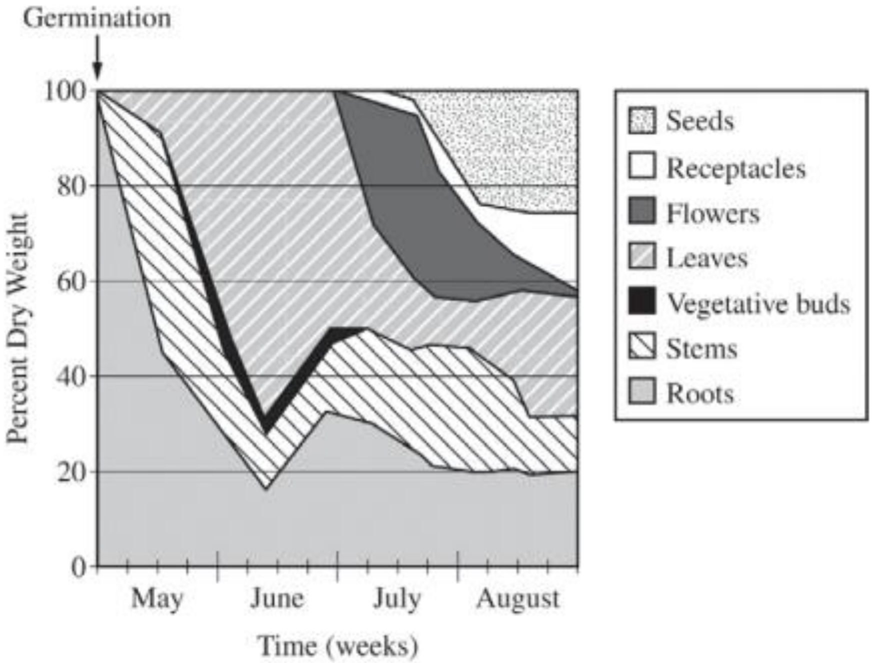


Figure 1. Percent dry weight of different plant structures during the growing season for an annual plant

The graph above illustrates the percent dry weight of different parts of a particular annual plant (plants that live less than one year) from early May to late August. The percent dry weight can be used to estimate the amount of energy a plant uses to produce its leaves, vegetative buds, stems, roots, and reproductive parts (seeds, receptacles, and flowers).

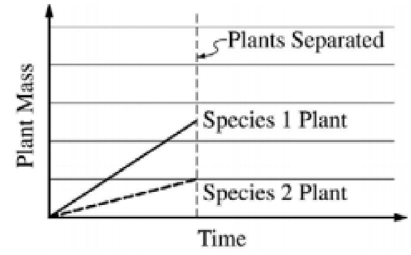
(a) **Identify** the direct source of energy used for plant growth during the first week of May, and **identify** the part of the plant that grew the most during the same period.

(b) Based on the data on the graph, **estimate** the percent of the total energy that the plant has allocated to the growth of leaves on the first day of July.

(c) Compared with perennials (plants that live more than two years), annual plants often allocate a much greater percentage of their total energy to growth of their reproductive parts in any given year. **Propose** ONE evolutionary advantage of the energy allocation strategy in annual plants compared with that in perennial plants.

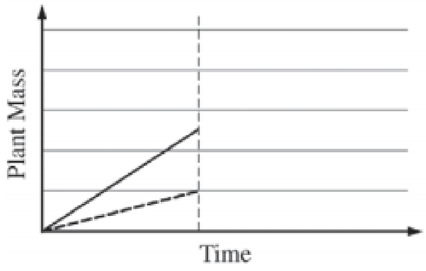
2016 #5

The graph below shows the mass of plants from two different species over time. The plants grew while attached to each other. The plants were separated at the time indicated by the vertical line in the graph.

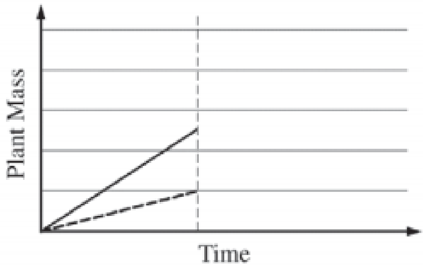


Using template 1, **graph** the predicted shape of the plant-mass lines after separation of the two plants if the plants were in an obligate mutualistic relationship. On template 2, **graph** the predicted shape of the plant-mass lines if the species 2 plant was a parasite of the species 1 plant. **Justify** each of your predictions.

TEMPLATE 1: OBLIGATE MUTUALISM



TEMPLATE 2: PARASITISM



2016 #8

Researchers conducted a study to investigate the effect of exercise on the release of prolactin into the blood. The researchers measured the concentration of prolactin in the blood of eight adult males before (T = 0 hour) and after one hour (T = 1 hour) of vigorous exercise. As a control, the researchers measured the concentration of blood prolactin in the same group of individuals at the same times of day one week later, but without having them exercise. The results are shown in Figure 1.

(a) **Justify** the use of the without-exercise treatment as the control in the study design.

(b) Using evidence from the specific treatments, ***describe*** whether prolactin release changes after exercise. **Justify** your answer.

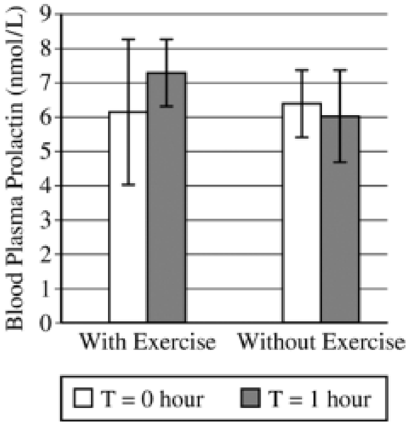


Figure 1. Effect of exercise on blood prolactin levels in adult males. The data represent the mean $\pm 2SE_{\bar{x}}$.

2015 #1

Many species have circadian rhythms that exhibit an approximately 24-hour cycle. Circadian rhythms are controlled by both genetics and environmental conditions, including light. Researchers investigated the effect of light on mouse behavior by using a running wheel with a motion sensor to record activity on actograms, as shown in Figure 1.

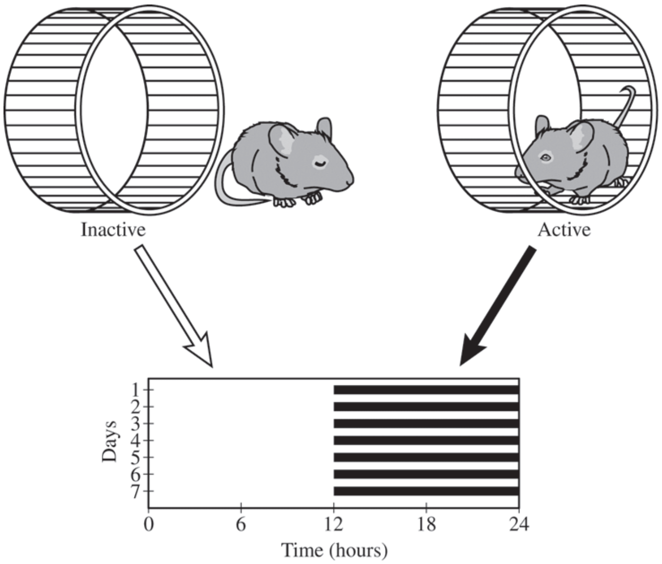


Figure 1. Strategy for recording mouse activity data. When a mouse is active on the running wheel, the activity is recorded as a dark horizontal line on an actogram. When the mouse is inactive, no dark line is recorded.

For the investigation, adult male mice were individually housed in cages in a soundproof room at 25°C. Each mouse was provided with adequate food, water, bedding material, and a running wheel. The mice were exposed to daily periods of 12 hours of light (L) and 12 hours of dark (D) (L12:D12) for 14 days, and their activity was continuously monitored. The activity data are shown in Figure 2.

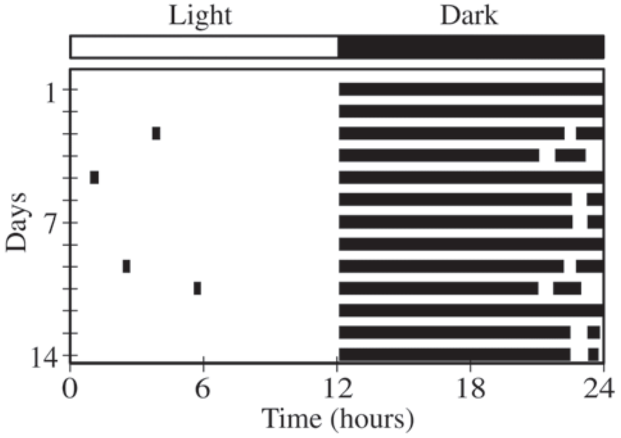


Figure 2. Actogram of mouse activity under L12:D12 conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

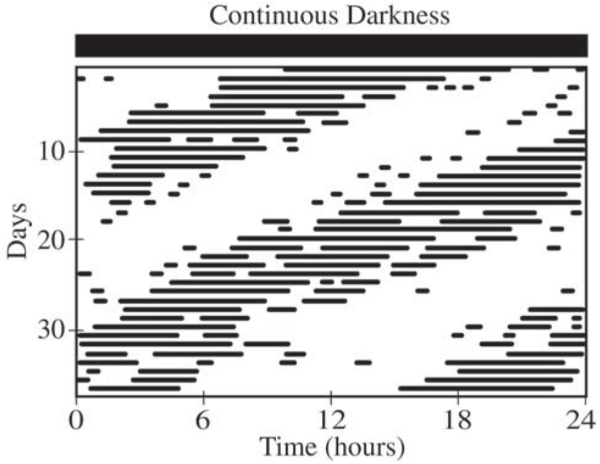


Figure 3. Actogram of mouse activity under DD conditions. Each row represents a 24-hour period, and the dark horizontal lines represent activity on the running wheel.

After 14 days in L12:D12, the mice were placed in continuous darkness (DD), and their activity on the running wheel was recorded as before. The activity data under DD conditions are shown in Figure 3.

NOTE: Part a, c, & d ARE OUT OF SCOPE FOR THE EXAM

(a) The nervous system plays a role in coordinating the observed activity pattern of the mice in response to light-dark stimuli. **Describe** ONE role of each of the following anatomical structures in responding to light-dark stimuli.

- A photoreceptor in the retina of the eye
- The brain
- A motor neuron

(b) Based on an analysis of the data in Figure 2, **describe** the activity pattern of the mice during the light and dark periods of the L12:D12 cycle.

(c) The researchers claim that the genetically controlled circadian rhythm in the mice does not follow a 24-hour cycle. **Describe** ONE difference between the daily pattern of activity under L12:D12 conditions (Figure 2) and under DD conditions (Figure 3), and use the data to **support** the researchers' claim.

(d) To investigate the claim that exposure to light overrides the genetically controlled circadian rhythm, the researchers plan to repeat the experiment with mutant mice lacking a gene that controls the circadian rhythm. **Predict** the observed activity pattern of the mutant mice under L12:D12 conditions and under DD conditions that would support the claim that light overrides the genetically controlled circadian rhythm.

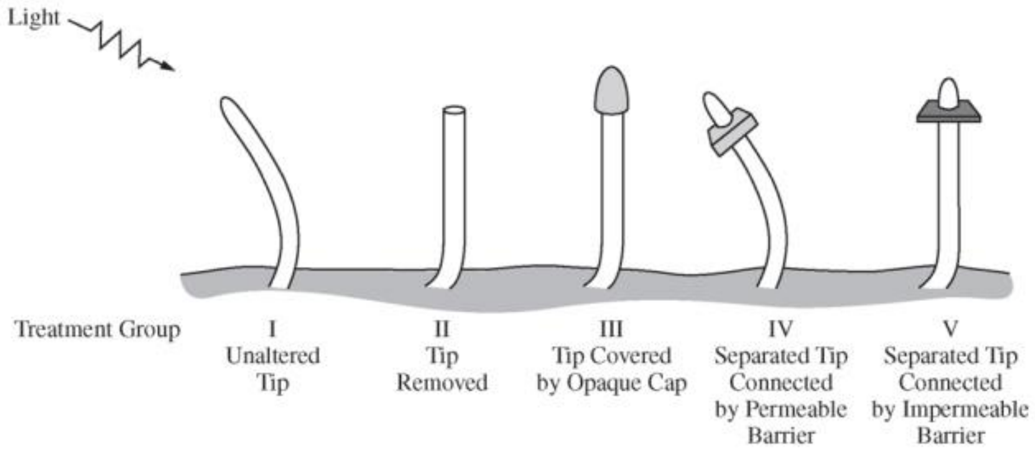
(e) In nature, mice are potential prey for some predatory birds that hunt during the day. **Describe** TWO features of a model that represents how the predator-prey relationship between the birds and the mice may have resulted in the evolution of the observed activity pattern of the mice.

2015 #5

Phototropism in plants is a response in which a plant shoot grows toward a light source. The results of five different experimental treatments from classic investigations of phototropism are shown below.

(a) **Give support** for the claim that the cells located in the tip of the plant shoot detect the light by comparing the results from treatment group I with the results from treatment group II and treatment group III.

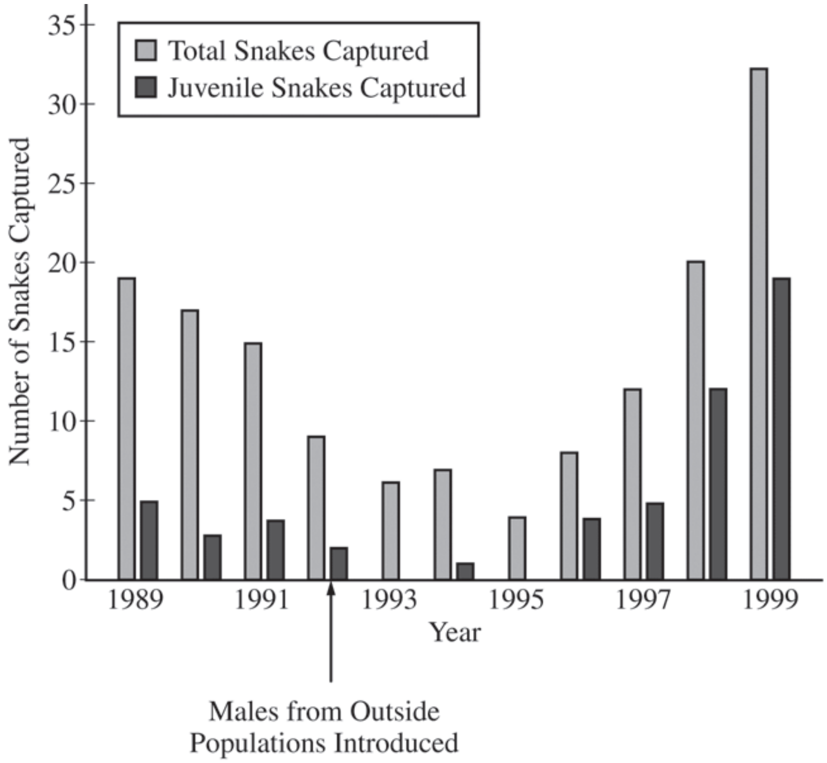
(b) In treatment groups IV and V, the tips of the plants are removed and placed back onto the shoot on either a permeable or impermeable barrier. Using the results from treatment groups IV and V, **describe** TWO additional characteristics of the phototropism response.


Light
Treatment Group
I
Unaltered Tip
II
Tip Removed
III
Tip Covered by Opaque Cap
IV
Separated Tip Connected by Permeable Barrier
V
Separated Tip Connected by Impermeable Barrier

2015 #6

In an attempt to rescue a small isolated population of snakes from decline, a few male snakes from several larger populations of the same species were introduced into the population in 1992. The snakes reproduce sexually, and there are abundant resources in the environment.

The figure below shows the results of a study of the snake population both before and after the introduction of the outside males. In the study, the numbers of captured snakes indicate the overall population size.



(a) **Describe** ONE characteristic of the original population that may have led to the population's decline in size between 1989 and 1993.

(b) **Propose** ONE reason that the introduction of the outside males rescued the snake population from decline.

(c) **Describe** how the data support the statement that there are abundant resources in the environment.

2014 #3

As part of a new suburban development, a sports complex consisting of athletic fields and buildings is constructed in a formerly wooded area.

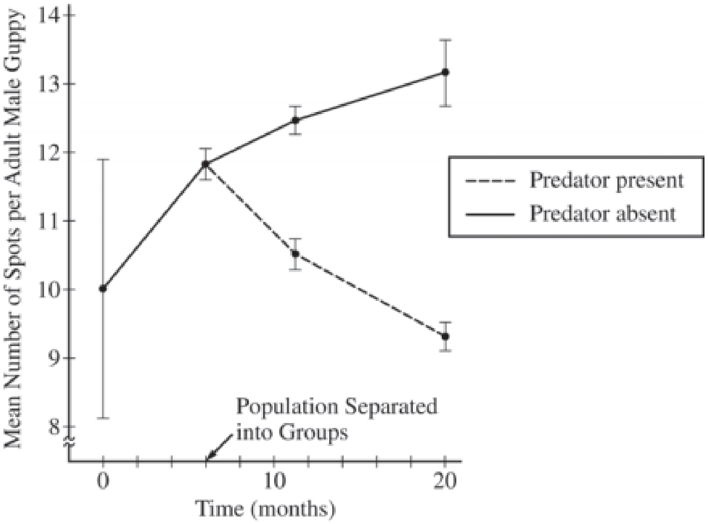
(a) **Predict** ONE ecological consequence on the local plant community that is likely to result during the site preparation and construction of the sports complex. **Justify** your predication.

(b) To maintain the playing fields, large quantities of water and chemicals are applied regularly to the grass-covered areas. **Predict** ONE effect on the local animal community that might result from regular use and maintenance of the playing fields. **Justify** your prediction.

2014 #4

Adult male guppies (*Poecilia reticulata*) exhibit genetically determined spots, while juvenile and adult female guppies lack spots. In a study of selection, male and female guppies from genetically diverse population were collected from different mountain streams and placed together in an isolated environment containing no predators.

The study population was maintained for several generations in the isolated area before being separated into two groups. One group was moved to an artificial pond containing a fish predator, while a second group was moved to an artifical pond containing no predators. The two groups went through several generations in their new environments. At different times during the experiment, the mean number of spots per adult male guppy was determined as shown in the figure below. Vertical bars in the figure represent two standard errors of the mean (SEM).



(a) **Describe** the change in genetic variation in the population between 0 and 6 months and **provide** reasoning for your description based on the means and SEM.

(b) **Propose** ONE type of mating behavior that could have resulted in the observed change in the number of spots per adult male guppy between 6 and 20 months in the absence of the predator.

(c) **Propose** an evolutionary mechanism that explains the change in average number of spots between 6 and 20 months in the presence of the predator.

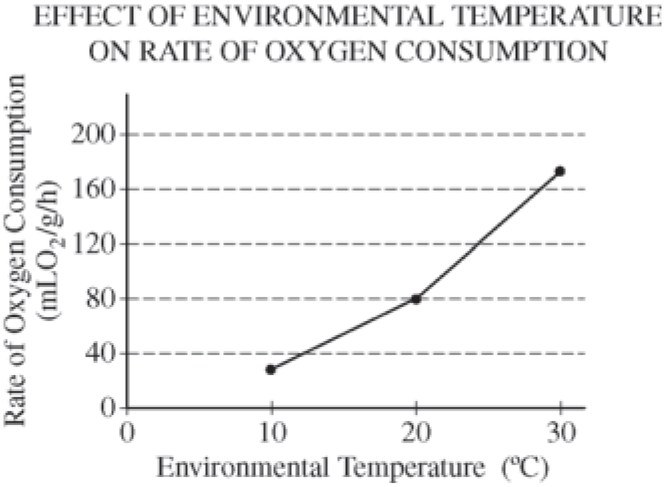
2014 #5

Genetically modifed crops have been developed that produce a protein that makes the plants resistant to insect pests. Other genetic modification make the crops more resistace to chemicals that kill plants (herbicides).

(a) **Describe** TWO potential biological risks of large-scale cultivation and use of such genetically modified plants.

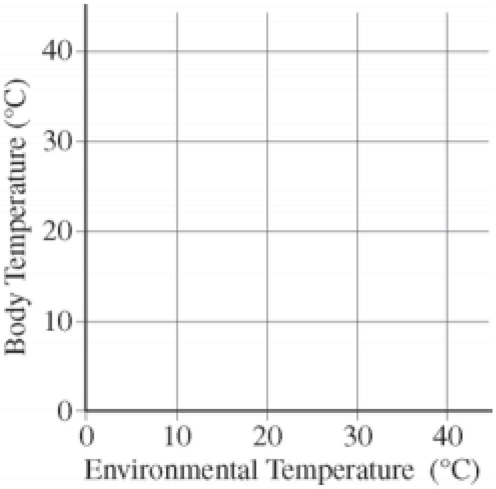
(b) For each of the risks you described in part (a), **propose** a practical approach for reducing the risk.

2014 #7

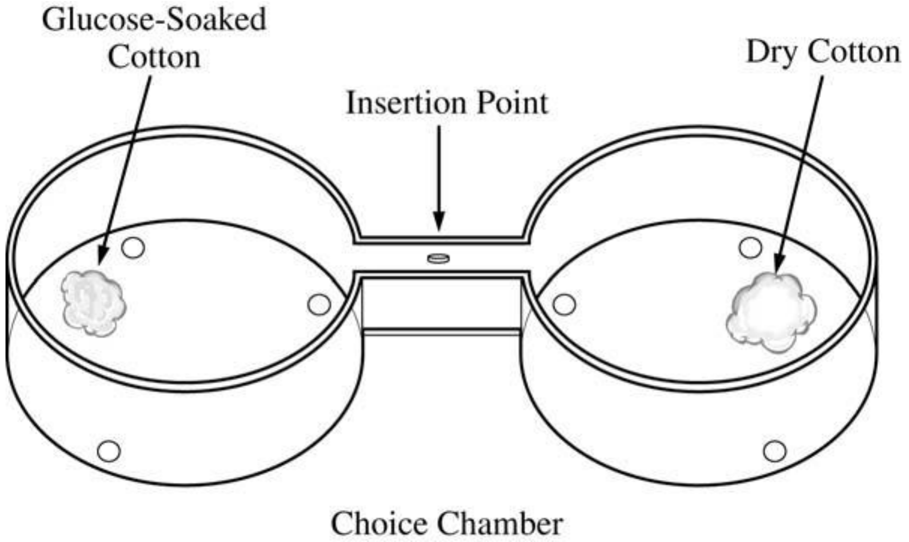


(a) Based on the graph, **describe** a specific method of thermoregulation used by the species of animal. **Provide** support for your answer using the data.

(b) On the labeled axis provided below, **draw** a line to indicate the most likely relationship between body temperature and environmental temperature in the species.



2013 #1



In an investigation of fruit-fly behavior, a covered choice chamber is used to test whether the spatial distribution of flies is affected by the presence of a substance placed at one end of the chamber. To test the flies' preference for glucose, 60 flies are introduced into the middle of the choice chamber at the insertion point indicated by the arrow in the figure above. A cotton ball soaked with a 10% glucose solution is placed at one end of the chamber, and a dry cotton ball with no solution is placed at the other end. The positions of flies are observed and recorded every minute for 10 minutes.

(a) **Predict** the distribution of flies in the chamber after 10 minutes and **justify** your prediction.

(b) **Propose** ONE specific improvement to each of the following parts of the experimental design and **explain** how the modification will affect the experiment.

- Experimental control
- Environmental factors

(c) The experiment described above is repeated with ripe bananas at one end and unripe bananas at the other end. Once again the positions of the flies are observed and recorded every minute for 10 minutes. The positions of flies after 1 minute and after 10 minutes are shown in the table below.

DISTRIBUTION OF FLIES IN CHOICE CHAMBER

Time (minutes)	Position in Chamber		
	End with Ripe Banana	Middle	End with Unripe Banana
1	21	18	21
10	45	3	12

Perform a chi-square test on the data for the 10-minute time point in the banana experiment. Specify the null hypothesis that you are testing and **enter** the values from your calculations in the table below.

(d) **Explain** whether your hypothesis is supported by the chi-square test and **justify** your explanation.

(e) Briefly **propose** a model that describes how environmental cues affect the behavior of the flies in the choice chamber.

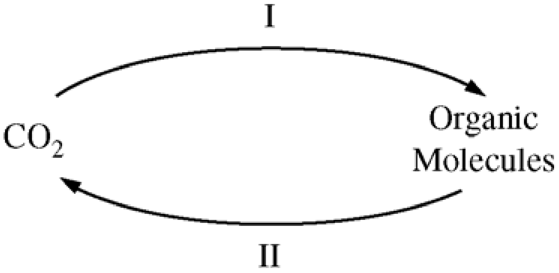
PART (C): CHI-SQUARE CALCULATIONS

Null Hypothesis:

	Observed (o)	Expected (e)	$(o-e)^2/e$
End with ripe banana			
Middle			
End with unripe banana			
Total			

2013 #4

Matter continuously cycles through an ecosystem. A simplified carbon cycle is depicted below.



(a) **Identify** the key metabolic process for step I and the key metabolic process for step II, and briefly **explain** how each process promotes movement of carbon through the cycle. For each process, your explanation should focus on the role of energy in the movement of carbon.

(b) **Identify** an organism that carries out both processes.

Free Response Scoring Guidelines

2025 #3

Course Content	Practice and Skill
8.6: Biodiversity • 8.6.A*: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. • 8.6.B*: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure. 8.7: Disruptions in Ecosystems • 8.7.D*: Explain how geological and meteorological activity leads to changes in ecosystem structure and dynamics.	1.A: Describe biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	Examples of acceptable responses may include the following: • (Removal of a keystone species) reduces biodiversity/diversity/resilience (of the ecosystem). • (Removal of a keystone species) will cause the ecosystem to collapse.
(b)	Examples of acceptable responses may include the following: • (A treatment group with) only buffelgrass planted • (A treatment group with) no native grass species
(c)	Examples of acceptable responses may include the following: • There will be no difference in/effect on the abundance/dry weight/height/size of buffelgrass (when grown alone as compared with) when grown with native plants. • There will be no difference in/effect on the abundance/dry weight/height/size of buffelgrass grown in drought and nondrought conditions.
(d)	Examples of acceptable responses may include the following: • (With fewer native plant species after a wildfire) buffelgrass will have less competition/no competition (for resources). • (With fewer native plant species after a wildfire) buffelgrass will have more resources (for growth, development, and reproduction).

Scoring Statistics

	Max Points:	**Mean Score:**
Part A	1.0	0.32
Part B	1.0	0.60
Part C	1.0	0.55
Part D	1.0	0.25

Overall Mean Score: 1.72

2024 #4

Course Content	Practice and Skill
8.4: Effect of Density on Populations • 8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment. 8.5: Community Ecology • 8.5.B: Explain how interactions within and among populations influence community structure. 8.6: Biodiversity • 8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. 8.7: Disruptions in Ecosystems • 8.7.B: Explain how invasive species affect ecosystem dynamics.	1.A: Describe biological concepts and processes. 1.C: Explain biological concepts and processes in applied contexts. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	• **(The resilience of the ecosystem) will decrease.**
(b)	**Accept one of the following:** • **(The addition of the wild oat) limits the resources available (to the native plants), resulting in a decrease (in the population size).** • **(The addition of the wild oat) enables the aphid population to increase/increases the exposure to viruses, resulting in a decrease (in the population size of the native bunchgrass).**
(c)	• **(The native bunchgrass population) will increase (in abundance).**
(d)	• **(Adding ladybugs) will decrease the number of aphids, which will cause a decrease in the transmission of/infection by plant viruses.**

Scoring Statistics	
Mean: 2.16	Standard Deviation: 1.34

2023 #3

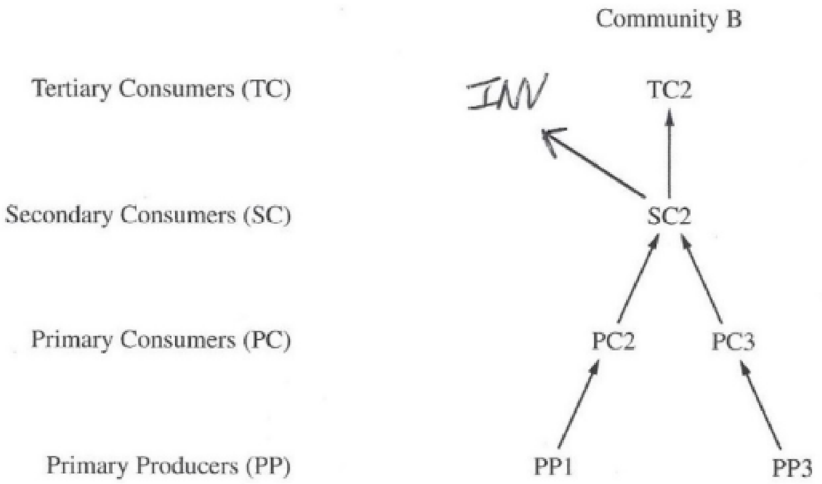
Course Content	Practice and Skill
8.6: Biodiversity • 8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. • 8.6.B: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure. 8.7: Disruptions in Ecosystems • 8.7.C: Describe human activities that lead to changes in ecosystem structure and dynamics.	1.A: Describe biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 3.C: Identify experimental procedures that align with the question 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part	Scoring Guidelines

(a)	**Describe** the effect of increased biodiversity on the resilience of an ecosystem in a changing environment. • (Ecosystem) resilience/it will be greater (with increased biodiversity).
(b)	**Justify** the scientists' selecting 5°C as the lowest temperature and 400 µatm as the lowest CO_2 level in their study of sand lance embryo survival. Accept one of the following: • These are the normal/current conditions at which the embryos develop and were used as a basis for comparison. • These (current) conditions were used as a basis to compare the effects of changes in environmental conditions/increases in temperature and CO_2.
(c)	**State** a null hypothesis for the experiment. Accept one of the following: • Climate change will have no effect on sand lance (embryo) survival/sand lance development/the size of sand lance populations. • (Increases in) temperature/CO_2 levels will have no effect on sand lance (embryo) survival/sand lance development /the size of sand lance populations. • There will be no difference in the sand lance (embryo) survival rates/sand lance development/the size of sand lance populations measured at all/different temperatures and CO_2 levels.
(d)	The scientists claim that a reduction in the population size of the *Ammodytes* sand lances will affect the stability of the entire coastal ecosystem. Provide reasoning to **support** the scientists' claim. Accept one of the following: • There will be a negative effect on other trophic levels because the sand lance provides food for many other species. • There will be a negative effect on other trophic levels because there will be reduced energy to transfer (to higher trophic levels).

Scoring Statistics	
Mean: 1.46	Standard Deviation: 1.16

2022 #5	
Course Content	Practice and Skill
8.6: Biodiversity • 8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. 8.7: Disruptions in Ecosystems • 8.7.B: Explain how invasive species affect ecosystem dynamics. • 8.7.C: Describe human activities that lead to changes in ecosystem structure and dynamics.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.
Part	Scoring Guidelines

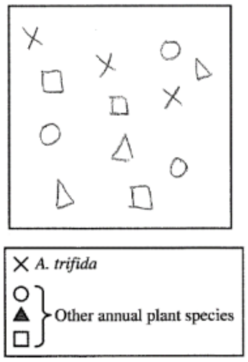
(a)	**Describe** a characteristic of a community that makes a species invasive in that community but not invasive in a different community. Accept one of the following: • There are no/reduced numbers of natural predators of the species in the community where it is invasive. • There are no/reduced numbers of competitors of the species in the community where it is invasive. • There are no/reduced numbers of diseases to which the species is susceptible in the community where it is invasive.
(b)	**Explain** why removing species PP1 will have a greater effect on community B than on community A. Accept one of the following: • In community B, there will be decreases in PC2, SC2, and TC2 /PC2, SC2, and PC3. In community A, PC2 has alternative food sources. • With fewer/less diverse primary producers (and primary consumers), there are fewer paths for energy to move through the community. • With fewer species/fewer feeding interactions/less diversity, community B will be less resilient to future environmental change.
(c)	An invasive species (INV) that eats individuals of species SC2 is introduced into community B. Using the template in the space provided for your response, for community B, indicate the feeding relationship for this invasive species by correctly placing **INV** to represent the invasive species and **an arrow** to represent the feeding relationship within community B. • INV should be added in a position that is horizontally aligned with TC2. An arrow should point from SC2 to INV.  Community B Tertiary Consumers (TC) Secondary Consumers (SC) Primary Consumers (PC) Primary Producers (PP) INV TC2 SC2 PC2 PC3 PP1 PP3

(d)	**Explain** how human activities that add toxins to the soil could change a community with many species at each trophic level, such as community A, into a community with few species at each trophic level, such as community B. Accept one of the following: • The activities could eliminate primary producers, which reduces species diversity at higher trophic levels. • The activities could cause biomagnification of the toxins, reducing species diversity at higher trophic levels.
Scoring Statistics	
Mean: 0.99	Standard Deviation: 0.94

2021 #5	
Course Content	Practice and Skill
8.4: Effect of Density on Populations • 8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment. 8.6: Biodiversity • 8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. 8.7: Disruptions in Ecosystems • 8.7.B: Explain how invasive species affect ecosystem dynamics.	1.A: Describe biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Part	Scoring Guidelines
(a)	**Describe** a cause of logistic growth of the ragweed population. Accept one of the following: • A factor that becomes limiting would cause the population size to stabilize. • Space/sunlight/herbivory/phosphorus/nitrogen/other density-dependent factor becomes limiting, and the population stabilizes.
(b)	Based on the representation in Figure 1, **explain** why the scientists claim that plot B would be more resilient than plot A in response to a sudden environmental change. • (Plot B is more resilient) because it has much greater (species) diversity than plot A does.

(c) In a third group of plots, the researchers removed all seedlings of all plants that germinated before June 1. All plants that germinated after June 1 were left untouched. Using the template in the space provided for your response and the symbols shown in Figure 1, **represent** the expected plant species that would be found in this third group of plots three months later. Draw no more than 12 symbols. Assume all other environmental conditions are the same as for the initial study described.



- All four species, including *A. trifida*, must be added to the template.

(d) **Explain** how an invasive species such as ragweed affects ecosystem biodiversity, as illustrated in Figure 1.

- The explanation requires a process or relationship - and must state that biodiversity decreases.
- Examples of appropriate responses include:
    - There are no predators of the invasive species, so its population grows faster and reduces biodiversity.
    - The invasive species germinates earlier, uses up resources, and reduces biodiversity.
    - The invasive species outcompetes other species and reduces biodiversity.

Scoring Statistics	
Mean: 1.62	Standard Deviation: 1.11

2019 #1

Course Content	Practice and Skill
4.4: Feedback • 4.4.A: Explain how positive and negative feedback helps maintain homeostasis. 7.2: Natural Selection • 7.2.A: Describe the importance of phenotypic variation in a population. 7.6: Evidence of Evolution • 7.6.A: Describe the types of data that provide evidence for evolution. 8.5: Community Ecology • 8.5.B: Explain how interactions within and among populations influence community structure.	1.A: Describe biological concepts and processes. 2.A: Describe characteristics of visual representations of biological concepts and processes. 2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

	6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	**Circle (1 point)** • Circle around either arrow pointing from a gene (*Trp-T* or *YUC*) to mRNA **Identification (1 point)** • IAA
(b)	**Prediction (1 point)** • Reduction in IAA production OR No production of IAA **Justification (1 point)** • The mutation will result in the translation of an inactive/nonfunctional Trp-T enzyme. • The mutation will result in no translation of the Trp-T enzyme. • The mutation will result in no/reduced production of I3PA.
(c)	**Explanation (2 points)** • Negative feedback/feedback inhibition/increasing amounts of IAA inhibits the pathway. • Production of YUC enzyme is inhibited OR YUC enzyme activity is inhibited.
(d)	**Identification (1 point)** • Mutualism **Description (1 point)** • Increases habitat/number of nodules for the rhizobacteria. • The bacteria receive carbon/carbon-containing molecules (as a result of increased plant growth).
(e)	**Description (1 point)** • Cheaters/bacteria that benefit without producing IAA/fixing nitrogen have more energy for reproduction. **Prediction (1 point)** • Decrease in the nitrogen-fixing/noncheater bacteria • Decrease in the amount of nitrogen fixed (by bacteria)

Scoring Statistics	
Mean: 4.98	Standard Deviation: 2.55

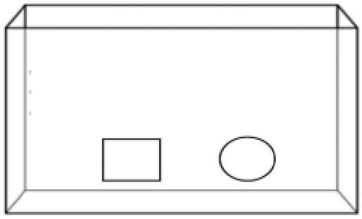
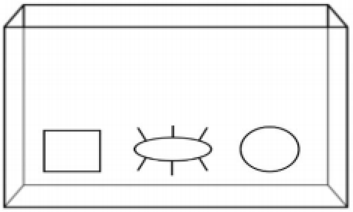
2019 #2

Course Content	Practice and Skill
2.7: Tonicity and Osmoregulation • 2.7.A: Explain how concentration gradients affect the movement of molecules across membranes. 8.3: Population Ecology • 8.3.A: Describe factors that influence growth dynamics of populations. 8.4: Effect of Density on Populations • 8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment. 8.5: Community Ecology	3.C: Identify experimental procedures that align with the question 4.A: Construct a graph to represent the data 6.A: Make a scientific claim. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

<table>
<tr><td>8.5.B: Explain how interactions within and among populations influence community structure.</td><td></td></tr>
<tr><th>Part</th><th>Scoring Guidelines</th></tr>
<tr><td>(a)</td><td>Completion (3 points)
Correctly plotted lines for remaining two treatments
Correctly labeled axes including units
Correctly labeled data lines</td></tr>
<tr><td>(b)</td><td>Reasoning (1 point)
Reduced initial population sizes keep the total number of organisms the same in all containers.
Reduced initial population sizes serve as a control for population density.</td></tr>
<tr><td>(c)</td><td>Evidence (1 point per row; 2 points max.)
<table>
<tr><th>Comparison of Groups</th><th>Evidence</th></tr>
<tr><td>I-A to II-A</td><td>Growth rate is faster in I/slower in II</td></tr>
<tr><td>I-A to II-A</td><td>Grows to a higher population density in I/lower population density in II</td></tr>
<tr><td>I-B to II-B</td><td>Growth rate is faster in I/slower in II</td></tr>
<tr><td>I-B to II-B</td><td>Grows to a higher population density in I/lower population density in II/ II dies out/II goes to zero</td></tr>
</table></td></tr>
<tr><td>(d)</td><td>Prediction (2 points)
Acceptable factors include:
Food
Space
Metabolic waste
Dissolved oxygen</td></tr>
<tr><td>(e)</td><td>Prediction (1 point)
The contractile vacuole will be more active.
Justification (1 point)
The environment is hypotonic with respect to the cell.
The cell is hypertonic with respect to environment.
Water has entered the cell (which could cause lysis).
The cell has lower water potential than the environment/the environment has higher water potential than the cell.</td></tr>
<tr><th colspan="2">Scoring Statistics</th></tr>
<tr><td>Mean: 4.53</td><td>Standard Deviation: 2.59</td></tr>
</table>

2018 #3	
Course Content	**Practice and Skill**
8.6: Biodiversity • 8.6.A: Describe the relationship between ecosystem diversity and its resilience to changes in the environment. • 8.6.B: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.	2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 3.B: State the null hypothesis or predict the results of an experiment.
Part	**Scoring Guidelines**

(a) **Drawing (2 points)**

Negative Control Aquarium (**1 point**)	Experimental Aquarium (**1 point**)
	

(b)

Identification (1 point maximum)	**Prediction (1 point maximum)**
Number/presence of pollen grains on female flowers OR pollination	More pollen grains transferred/pollination seen in experimental aquarium
Number/presence of fertilized plants/flowers OR fertilization	More fertilized plants/flowers/fertilization seen in experimental aquarium
Number/presence of seed/fruit/offspring produced OR reproduction	More seeds/fruits/offspring produced/reproduction in experimental aquarium

Scoring Statistics	
Mean: 2.38	Standard Deviation: 1.23

2018 #5

Course Content	Practice and Skill
8.5: Community Ecology • 8.5.B: Explain how interactions within and among populations influence community structure.	1.A: Describe biological concepts and processes. 2.A: Describe characteristics of visual representations of biological concepts and processes. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems.

Part	Scoring Guidelines
(a)	**Description (1 point)** • Cuckoos are parasites (of the warbler). • The cuckoo benefits from the relationship, and the warbler is harmed by the relationship.
(b)	**Graph (2 points)** • Cuckoo added (group 1): Bar must be HIGHER than the “Warblers Only” bar. • Cuckoo removed (group 2): Bar must be LOWER than the “Warblers and Cuckoos” bar.
(c)	**Identification (1 point)** • Mutualism • Both organisms benefit

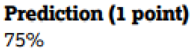
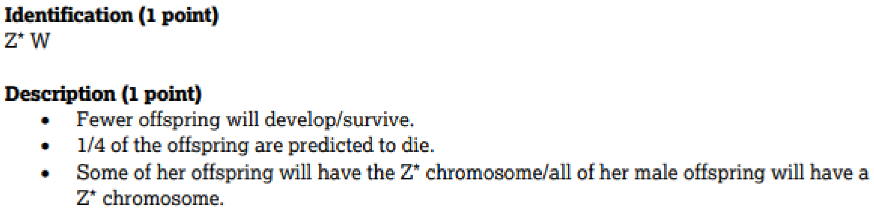
Scoring Statistics	
Mean: 2.66	Standard Deviation: 1.19

2018 #7

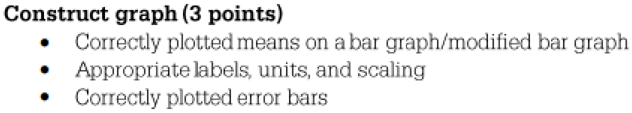
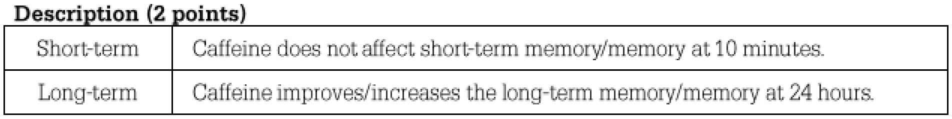
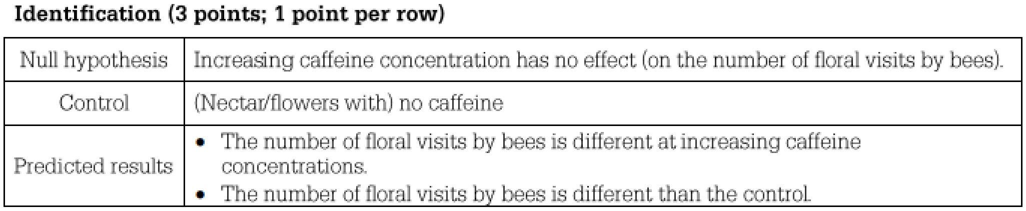
Course Content	Practice and Skill
5.5: Environmental Effects on Phenotype • 5.5.A: Explain how the same genotype can result in multiple phenotypes under different environmental conditions. 8.1: Responses to the Environment	2.A: Describe characteristics of visual representations of biological concepts and processes. 3.B: State the null hypothesis or predict the results of an experiment. 5.A: Perform mathematical calculations 6.A: Make a scientific claim.

<table>
<tr><td colspan="2">

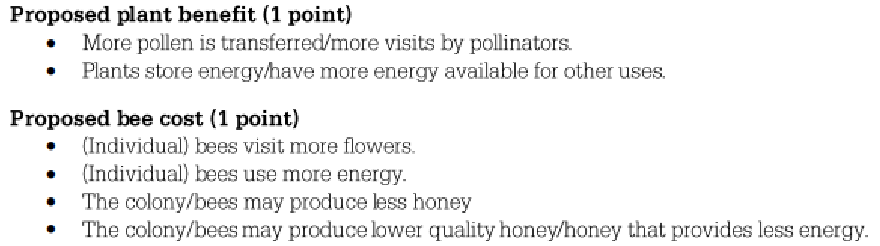
- 8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.

</td><td></td></tr>
<tr><td>Part</td><td colspan="2">Scoring Guidelines</td></tr>
<tr><td>(a)</td><td colspan="2">
Prediction (1 point)
75%</td></tr>
<tr><td>(b)</td><td colspan="2">
Identification (1 point)
Z* W

Description (1 point)
• Fewer offspring will develop/survive.
• 1/4 of the offspring are predicted to die.
• Some of her offspring will have the Z* chromosome/all of her male offspring will have a Z* chromosome.</td></tr>
<tr><td colspan="3">Scoring Statistics</td></tr>
<tr><td colspan="2">Mean: 1.10</td><td>Standard Deviation: 1.15</td></tr>
</table>

<table>
<tr><th colspan="3">2017 #1</th></tr>
<tr><td colspan="2">Course Content</td><td>Practice and Skill</td></tr>
<tr><td colspan="2">8.1: Responses to the Environment
8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.
8.1.B: Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.</td><td>3.B: State the null hypothesis or predict the results of an experiment.
3.C: Identify experimental procedures that align with the question
3.D: Propose a new investigation based on an evaluation of the experimental design or evidence.
4.A: Construct a graph to represent the data
4.B: Describe data from a table or graph
6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.</td></tr>
<tr><td>Part</td><td colspan="2">Scoring Guidelines</td></tr>
<tr><td>(a)</td><td colspan="2">
Construct graph (3 points)
• Correctly plotted means on a bar graph/modified bar graph
• Appropriate labels, units, and scaling
• Correctly plotted error bars</td></tr>
<tr><td>(b)</td><td colspan="2">
Description (2 points)<table><tr><td>Short-term</td><td>Caffeine does not affect short-term memory/memory at 10 minutes.</td></tr><tr><td>Long-term</td><td>Caffeine improves/increases the long-term memory/memory at 24 hours.</td></tr></table></td></tr>
<tr><td>(c)</td><td colspan="2">
Identification (3 points; 1 point per row)<table><tr><td>Null hypothesis</td><td>Increasing caffeine concentration has no effect (on the number of floral visits by bees).</td></tr><tr><td>Control</td><td>(Nectar/flowers with) no caffeine</td></tr><tr><td>Predicted results</td><td>• The number of floral visits by bees is different at increasing caffeine concentrations.
• The number of floral visits by bees is different than the control.</td></tr></table></td></tr>
</table>

(d)



Proposed plant benefit (1 point)
- More pollen is transferred/more visits by pollinators.
- Plants store energy/have more energy available for other uses.

Proposed bee cost (1 point)
- (Individual) bees visit more flowers.
- (Individual) bees use more energy.
- The colony/bees may produce less honey
- The colony/bees may produce lower quality honey/honey that provides less energy.

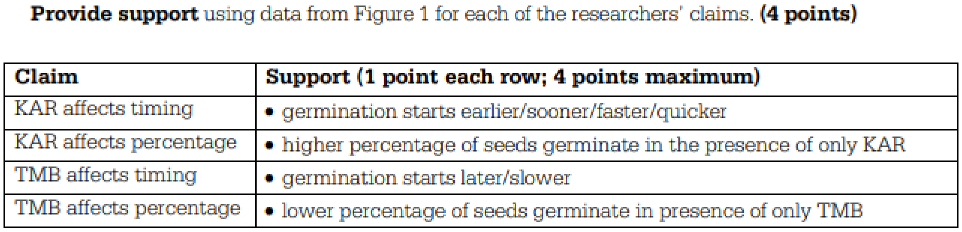
Scoring Statistics	
Mean: 3.83	Standard Deviation: 2.58

2017 #2

Course Content	Practice and Skill
7.2: Natural Selection • 7.2.B: Explain how variation in molecules within cells connects to the fitness of an organism. 8.5: Community Ecology • 8.5.B: Explain how interactions within and among populations influence community structure.	1.A: Describe biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data.

Part | Scoring Guidelines

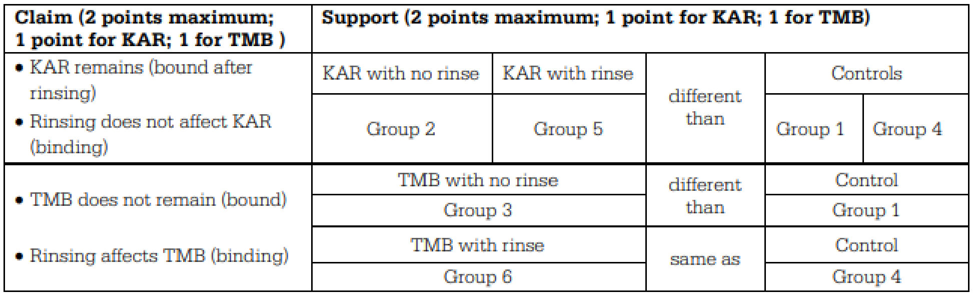
(a)



Provide support using data from Figure 1 for each of the researchers' claims. **(4 points)**

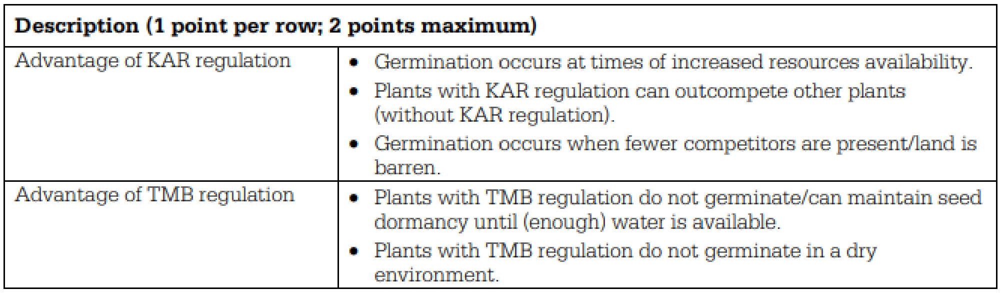
Claim	**Support (1 point each row; 4 points maximum)**
KAR affects timing	• germination starts earlier/sooner/faster/quicker
KAR affects percentage	• higher percentage of seeds germinate in the presence of only KAR
TMB affects timing	• germination starts later/slower
TMB affects percentage	• lower percentage of seeds germinate in presence of only TMB

(b)



Claim (2 points maximum; 1 point for KAR; 1 for TMB)	**Support (2 points maximum; 1 point for KAR; 1 for TMB)**				
• KAR remains (bound after rinsing) • Rinsing does not affect KAR (binding)	KAR with no rinse	KAR with rinse	different than	Controls	
	Group 2	Group 5		Group 1	Group 4
• TMB does not remain (bound)	TMB with no rinse		different than	Control	
	Group 3			Group 1	
• Rinsing affects TMB (binding)	TMB with rinse		same as	Control	
	Group 6			Group 4	

(c)

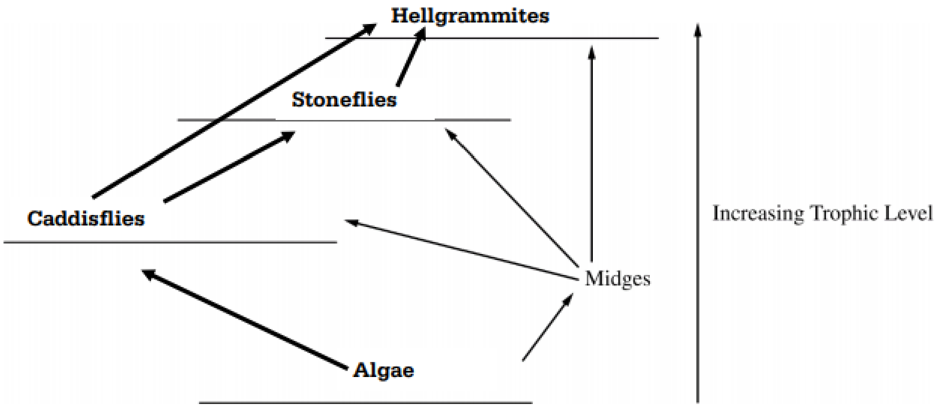


Description (1 point per row; 2 points maximum)	
Advantage of KAR regulation	• Germination occurs at times of increased resources availability. • Plants with KAR regulation can outcompete other plants (without KAR regulation). • Germination occurs when fewer competitors are present/land is barren.
Advantage of TMB regulation	• Plants with TMB regulation do not germinate/can maintain seed dormancy until (enough) water is available. • Plants with TMB regulation do not germinate in a dry environment.

Scoring Statistics	
Mean: 4.04	Standard Deviation: 2.83

2017 #4

Course Content	Practice and Skill
8.2: Energy Flow Through Ecosystems - 8.2.C: Explain how changes in energy availability affect populations, communities, and ecosystems. 8.5: Community Ecology - 8.5.A: Describe the structure of a community according to its species composition and diversity. 8.6: Biodiversity - 8.6.B: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure.	2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines
(a)	**Construction of food web (2 points maximum)** - All four organisms placed on the appropriate lines - All four arrows correctly drawn between organisms  Hellgrammites Stoneflies Caddisflies Midges Algae Increasing Trophic Level
(b)	**Prediction (1 point)** - Stoneflies **Justification (1 point)** - Stoneflies have a higher dependence on the midges than do the hellgrammites and caddisflies. - Midges are 90 percent of the stonefly diet, while 30 percent of the caddisfly and 10 percent of the hellgrammite diet are midges.

Scoring Statistics	
Mean: 2.05	Standard Deviation: 1.27

2016 #2

Course Content	Practice and Skill
6.5: Regulation of Gene Expression - 6.5.A: Describe the types of interactions that regulate gene expression. 8.3: Population Ecology - 8.3.A: Describe factors that influence growth dynamics of populations.	4.B: Describe data from a table or graph 5.A: Perform mathematical calculations 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines

(a)	**Estimate (1 point)** - 10^8 **Description (1 point)** - When both nutrients are depleted
(b)	**Calculation (1 point)** - 4,995
(c)	**Identification (1 point)** - Nutrient I is the preferred nutrient. **Justification (1 point)** - When both nutrients are present in the growth medium, only nutrient I is used. - Nutrient II is only used after nutrient I is depleted. **Proposed advantage (1 point)** - Do not spend energy making enzymes/proteins that the cell doesn't need. - Do not have to express all metabolic genes at once. - The preferred nutrient provides more energy.
(d)	**Description (2 points)** - Nutrient I promotes expression of genes required for metabolism of nutrient I. - Nutrient I represses expression of genes required for metabolism of nutrient II. **Reasoning (2 points)** - Nutrient I is depleted from the growth medium OR neither nutrient is being consumed. - Takes time to produce proteins/enzymes required to metabolize nutrient II.
Scoring Statistics	
Mean: 3.09	Standard Deviation: 2.20

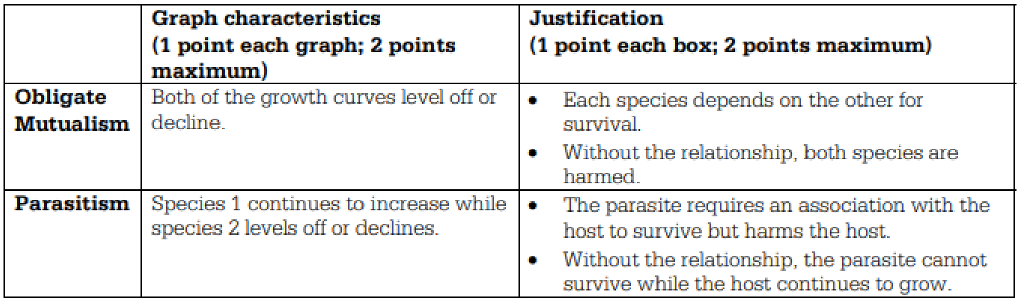
2016 #3	
Course Content	Practice and Skill
7.1: Introduction to Natural Selection - 7.1.B: Explain how natural selection affects populations. 7.2: Natural Selection - 7.2.B: Explain how variation in molecules within cells connects to the fitness of an organism. 8.2: Energy Flow Through Ecosystems - 8.2.A: Describe the strategies organisms use to acquire and use energy.	2.A: Describe characteristics of visual representations of biological concepts and processes. 5.A: Perform mathematical calculations 6.A: Make a scientific claim.
Part	Scoring Guidelines
(a)	**Identify direct source of energy (1 point)** - Seed - Stored organic nutrients/carbohydrates **Identify plant part (1 point)** - Roots
(b)	**Identification (1 point)** - Any value between 45-55 percent
(c)	**Proposed advantage (1 point)** - Increased chance of reproduction before the plants die. - If the plants do not use the strategy, they decrease the likelihood they will ever reproduce.

Scoring Statistics	
Mean: 1.36	Standard Deviation: 0.96

2016 #5

Course Content	Practice and Skill
8.5: Community Ecology • 8.5.B: Explain how interactions within and among populations influence community structure.	6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part	Scoring Guidelines



	Graph characteristics (1 point each graph; 2 points maximum)	**Justification (1 point each box; 2 points maximum)**
Obligate Mutualism	Both of the growth curves level off or decline.	• Each species depends on the other for survival. • Without the relationship, both species are harmed.
Parasitism	Species 1 continues to increase while species 2 levels off or declines.	• The parasite requires an association with the host to survive but harms the host. • Without the relationship, the parasite cannot survive while the host continues to grow.

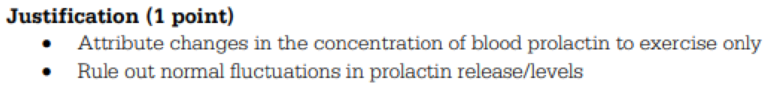
Scoring Statistics	
Mean: 1.92	Standard Deviation: 1.68

2016 #8

Course Content	Practice and Skill
4.4: Feedback • 4.4.A: Explain how positive and negative feedback helps maintain homeostasis. 8.1: Responses to the Environment • 8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.	3.C: Identify experimental procedures that align with the question 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different.

Part	Scoring Guidelines

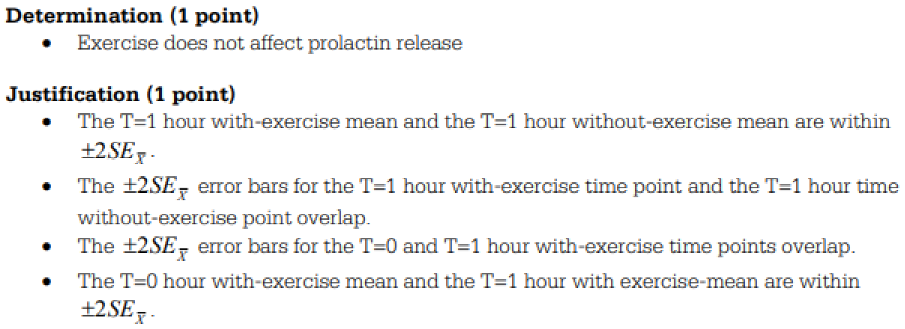
(a)



Justification (1 point)

- Attribute changes in the concentration of blood prolactin to exercise only
- Rule out normal fluctuations in prolactin release/levels

(b)



Determination (1 point)

- Exercise does not affect prolactin release

Justification (1 point)

- The T=1 hour with-exercise mean and the T=1 hour without-exercise mean are within $\pm 2SE_{\bar{x}}$.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=1 hour with-exercise time point and the T=1 hour time without-exercise point overlap.
- The $\pm 2SE_{\bar{x}}$ error bars for the T=0 and T=1 hour with-exercise time points overlap.
- The T=0 hour with-exercise mean and the T=1 hour with exercise-mean are within $\pm 2SE_{\bar{x}}$.

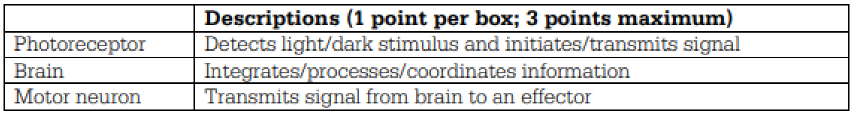
Scoring Statistics	
Mean: 0.56	Standard Deviation: 0.66

2015 #1

Course Content	Practice and Skill
4.4: Feedback • 4.4.A: Explain how positive and negative feedback helps maintain homeostasis.	2.A: Describe characteristics of visual representations of biological concepts and processes. 6.A: Make a scientific claim.

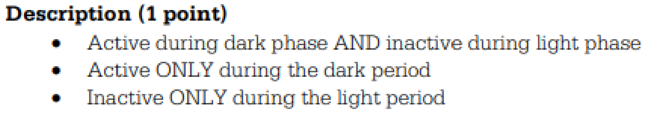
Part | **Scoring Guidelines**

(a)



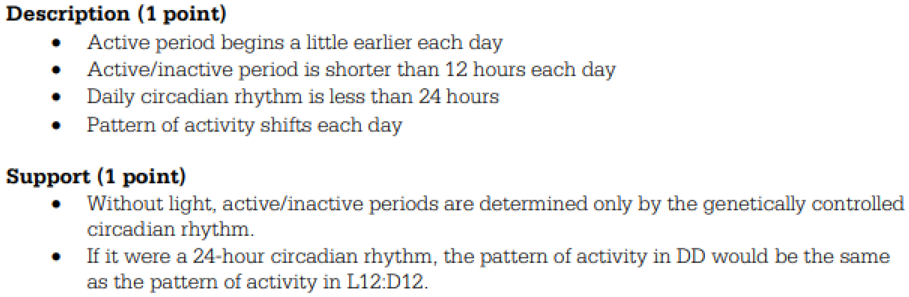
	Descriptions (1 point per box; 3 points maximum)
Photoreceptor	Detects light/dark stimulus and initiates/transmits signal
Brain	Integrates/processes/coordinates information
Motor neuron	Transmits signal from brain to an effector

(b)



Description (1 point)
- Active during dark phase AND inactive during light phase
- Active ONLY during the dark period
- Inactive ONLY during the light period

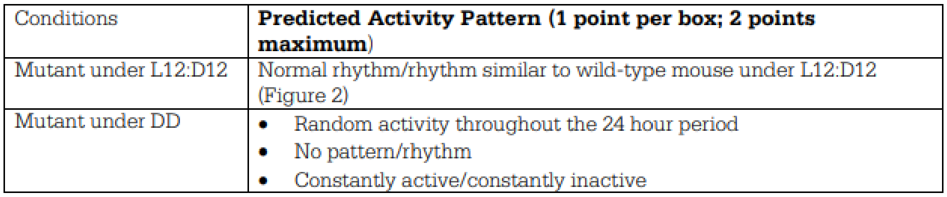
(c)



Description (1 point)
- Active period begins a little earlier each day
- Active/inactive period is shorter than 12 hours each day
- Daily circadian rhythm is less than 24 hours
- Pattern of activity shifts each day

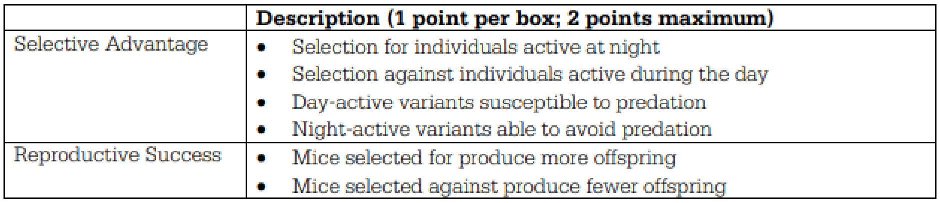
Support (1 point)
- Without light, active/inactive periods are determined only by the genetically controlled circadian rhythm.
- If it were a 24-hour circadian rhythm, the pattern of activity in DD would be the same as the pattern of activity in L12:D12.

(d)



Conditions	**Predicted Activity Pattern (1 point per box; 2 points maximum)**
Mutant under L12:D12	Normal rhythm/rhythm similar to wild-type mouse under L12:D12 (Figure 2)
Mutant under DD	• Random activity throughout the 24 hour period • No pattern/rhythm • Constantly active/constantly inactive

(e)



	Description (1 point per box; 2 points maximum)
Selective Advantage	• Selection for individuals active at night • Selection against individuals active during the day • Day-active variants susceptible to predation • Night-active variants able to avoid predation
Reproductive Success	• Mice selected for produce more offspring • Mice selected against produce fewer offspring

Scoring Statistics

Mean: 3.81	Standard Deviation: 2.33

2015 #5

Course Content	Practice and Skill
8.1: Responses to the Environment • 8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.	5.D: Use data to evaluate a hypothesis or prediction, including rejecting or failing to reject the null hypothesis. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

Part | **Scoring Guidelines**

(a)	**Support (2 points maximum)** • In treatment II the tip is removed and the plant no longer bends toward light. • In treatment III the cap blocks the light to the tip and the plant no longer bends toward light.
(b)	**Description (2 points maximum)** • Tip produces a substance/signal/hormone (auxin) in response to light causing the plants to bend • Substance must diffuse from the tip causing the plants to bend

Scoring Statistics	
Mean: 1.95	Standard Deviation: 1.21

2015 #6

Course Content	Practice and Skill
8.3: Population Ecology • 8.3.A: Describe factors that influence growth dynamics of populations. 8.4: Effect of Density on Populations • 8.4.A: Explain how the density of a population affects and is determined by resource availability in the environment. 8.7: Disruptions in Ecosystems • 8.7.A: Explain the interaction between the environment and random or preexisting variations in populations.	1.A: Describe biological concepts and processes. 6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part	Scoring Guidelines
(a)	**Description (1 point)** • Lacked genetic diversity/variation • Was an aged/post-reproductive population/not enough young snakes • Had unfavorable sex ratio/too few males • Possessed a harmful mutation/disease
(b)	**Proposal (1 point)** • Increased genetic diversity in the population • Increased reproductive success • Established beneficial sex ratio/sufficient proportion of males for reproduction • Introduced resistance to disease that was affecting the original population
(c)	**Description (1 point)** • Population can/does grow • If resources are limited population would not grow

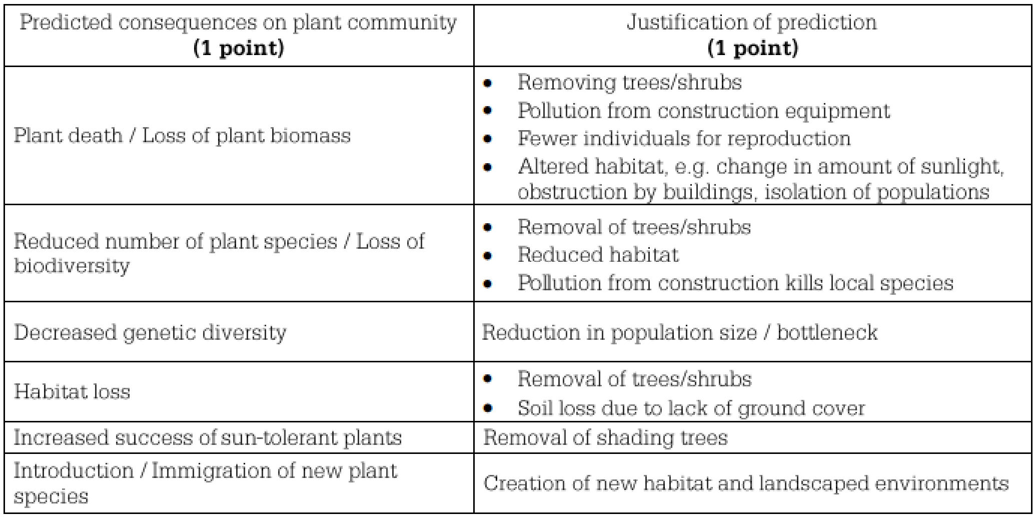
Scoring Statistics	
Mean: 1.95	Standard Deviation: 1.06

2014 #3

Course Content	Practice and Skill
8.6: Biodiversity • 8.6.B: Explain how the addition or removal of any component of an ecosystem will affect its overall short-term and long-term structure. 8.7: Disruptions in Ecosystems	6.C: Provide reasoning to justify a claim by connecting evidence to biological theories. 6.E: Predict the causes or effects of a change in, or disruption to, one or more components in a biological system.

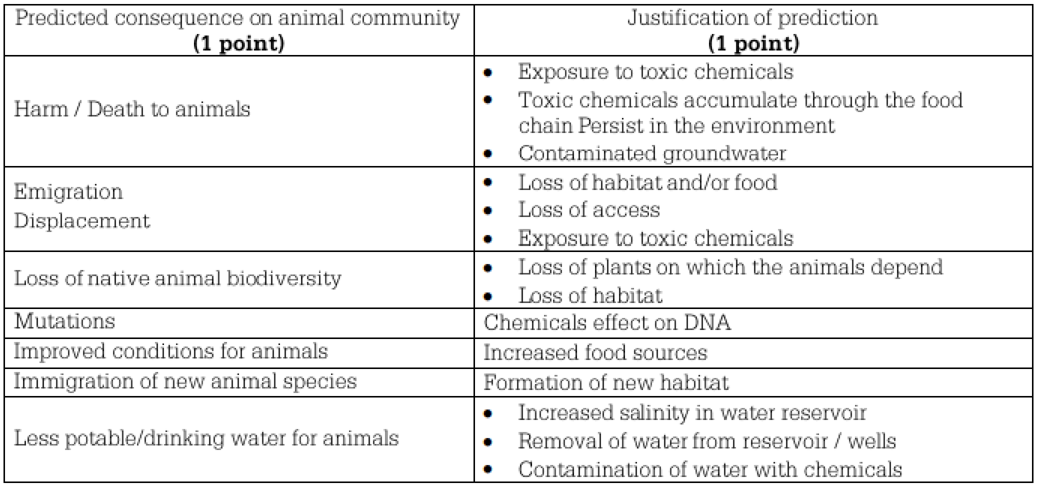
- 8.7.C: Describe human activities that lead to changes in ecosystem structure and dynamics.

Part	Scoring Guidelines
(a)	



Predicted consequences on plant community **(1 point)**	Justification of prediction **(1 point)**
Plant death / Loss of plant biomass	• Removing trees/shrubs • Pollution from construction equipment • Fewer individuals for reproduction • Altered habitat, e.g. change in amount of sunlight, obstruction by buildings, isolation of populations
Reduced number of plant species / Loss of biodiversity	• Removal of trees/shrubs • Reduced habitat • Pollution from construction kills local species
Decreased genetic diversity	Reduction in population size / bottleneck
Habitat loss	• Removal of trees/shrubs • Soil loss due to lack of ground cover
Increased success of sun-tolerant plants	Removal of shading trees
Introduction / Immigration of new plant species	Creation of new habitat and landscaped environments

Part	Scoring Guidelines
(b)	



Predicted consequence on animal community **(1 point)**	Justification of prediction **(1 point)**
Harm / Death to animals	• Exposure to toxic chemicals • Toxic chemicals accumulate through the food chain Persist in the environment • Contaminated groundwater
Emigration Displacement	• Loss of habitat and/or food • Loss of access • Exposure to toxic chemicals
Loss of native animal biodiversity	• Loss of plants on which the animals depend • Loss of habitat
Mutations	Chemicals effect on DNA
Improved conditions for animals	Increased food sources
Immigration of new animal species	Formation of new habitat
Less potable/drinking water for animals	• Increased salinity in water reservoir • Removal of water from reservoir / wells • Contamination of water with chemicals

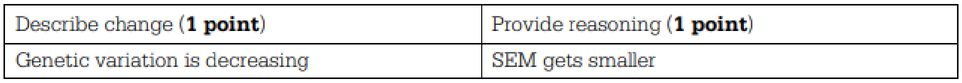
Scoring Statistics	
Mean: 3.34	Standard Deviation: 1.10

2014 #4

Course Content	Practice and Skill
7.1: Introduction to Natural Selection • 7.1.B: Explain how natural selection affects populations. 7.5: Hardy-Weinberg Equilibrium • 7.5.A: Describe the conditions under which allele and genotype frequencies will change in populations. 8.1: Responses to the Environment • 8.1.B: Explain how the behavioral responses of organisms affect their overall fitness and may contribute to the success of a population.	1.C: Explain biological concepts and processes in applied contexts. 4.B: Describe data from a table or graph 5.B: Use confidence intervals and error bars to estimate whether sample means are statistically different. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

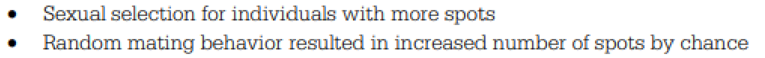
Part	Scoring Guidelines

(a)



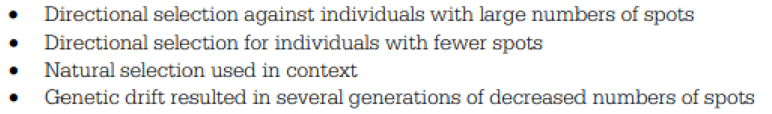
Describe change (**1 point**)	Provide reasoning (**1 point**)
Genetic variation is decreasing	SEM gets smaller

(b)



- Sexual selection for individuals with more spots
- Random mating behavior resulted in increased number of spots by chance

(c)



- Directional selection against individuals with large numbers of spots
- Directional selection for individuals with fewer spots
- Natural selection used in context
- Genetic drift resulted in several generations of decreased numbers of spots

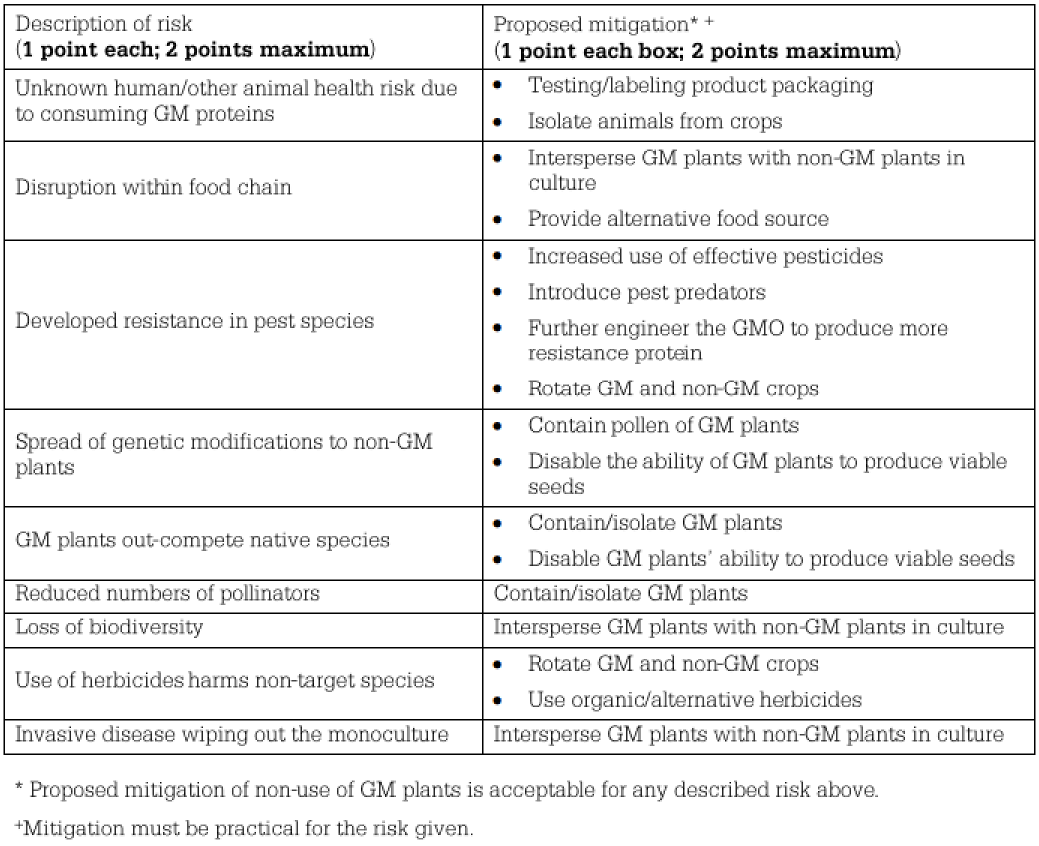
Scoring Statistics

Mean: 1.37	Standard Deviation: 1.15

2014 #5

Course Content	Practice and Skill
6.8: Biotechnology • 6.8.A: Explain the use of genetic engineering techniques in analyzing or manipulating DNA. 7.3: Artificial Selection • 7.3.A: Explain how humans can affect diversity within a population. 8.7: Disruptions in Ecosystems • 8.7.C: Describe human activities that lead to changes in ecosystem structure and dynamics.	6.B: Support a claim with evidence from biological principles, concepts, processes, and data. 6.C: Provide reasoning to justify a claim by connecting evidence to biological theories.

Part | Scoring Guidelines



Description of risk (**1 point each; 2 points maximum**)	Proposed mitigation* + (**1 point each box; 2 points maximum**)
Unknown human/other animal health risk due to consuming GM proteins	• Testing/labeling product packaging • Isolate animals from crops
Disruption within food chain	• Intersperse GM plants with non-GM plants in culture • Provide alternative food source
Developed resistance in pest species	• Increased use of effective pesticides • Introduce pest predators • Further engineer the GMO to produce more resistance protein • Rotate GM and non-GM crops
Spread of genetic modifications to non-GM plants	• Contain pollen of GM plants • Disable the ability of GM plants to produce viable seeds
GM plants out-compete native species	• Contain/isolate GM plants • Disable GM plants' ability to produce viable seeds
Reduced numbers of pollinators	Contain/isolate GM plants
Loss of biodiversity	Intersperse GM plants with non-GM plants in culture
Use of herbicides harms non-target species	• Rotate GM and non-GM crops • Use organic/alternative herbicides
Invasive disease wiping out the monoculture	Intersperse GM plants with non-GM plants in culture

* Proposed mitigation of non-use of GM plants is acceptable for any described risk above.

+Mitigation must be practical for the risk given.

Scoring Statistics

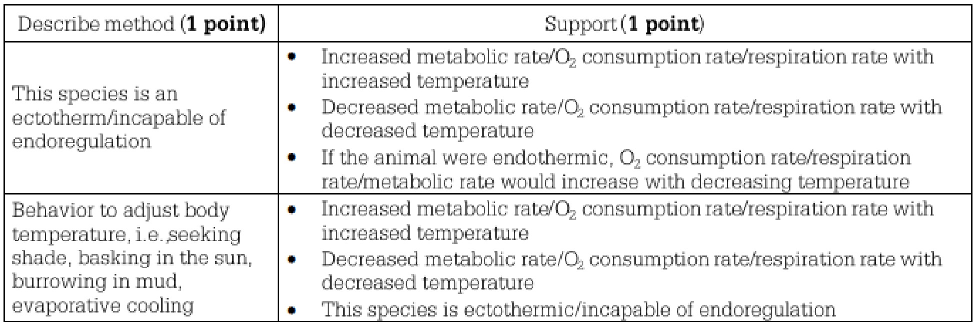
Mean: 1.78	Standard Deviation: 1.38

2014 #7

Course Content	Practice and Skill
8.1: Responses to the Environment - 8.1.A: Explain how the behavioral and physiological response of an organism is related to changes in internal or external environment.	2.B: Explain relationships between characteristics of biological models in both theoretical and applied contexts. 2.C: Explain how biological models relate to larger principles, concepts, processes, systems, or theories. 2.D: Represent relationships within biological models, including mathematical models, diagrams, flowcharts, and systems. 4.A: Construct a graph to represent the data

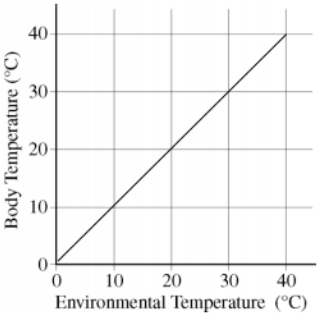
Part	Scoring Guidelines

(a)



Describe method (**1 point**)	Support (**1 point**)
This species is an ectotherm/incapable of endoregulation	- Increased metabolic rate/O_2 consumption rate/respiration rate with increased temperature - Decreased metabolic rate/O_2 consumption rate/respiration rate with decreased temperature - If the animal were endothermic, O_2 consumption rate/respiration rate/metabolic rate would increase with decreasing temperature
Behavior to adjust body temperature, i.e. seeking shade, basking in the sun, burrowing in mud, evaporative cooling	- Increased metabolic rate/O_2 consumption rate/respiration rate with increased temperature - Decreased metabolic rate/O_2 consumption rate/respiration rate with decreased temperature - This species is ectothermic/incapable of endoregulation

(b)



- Line/curve with positive slope

Scoring Statistics	
Mean: 0.90	Standard Deviation: 0.94

2013 #1

Course Content	Practice and Skill

Part	Scoring Guidelines
(a)	- 1 point for predicting the location of the flies in the choice chamber - 1 point for justifying the prediction

(b)

	Proposed Improvement (includes but not limited to) (**1 point maximum**)	Explanation (**1 point maximum**)
Experimental control	Replace the dry cotton ball with a water-soaked cotton ball.	Ensures that glucose is the attractant
	Constant light or temperature or duration of experiment or time of day, etc.	Other variables must be held constant

	Proposed Improvement (includes but not limited to) (**1 point maximum**)	Explanation (**1 point maximum**)
Environmental factors	• Use different concentrations of glucose • Use different temperature(s) • Use different light levels • Use a different choice chamber (size/shape) • Vary duration of the experiment • Vary time of day when experiment is performed	Attributes movement of flies only to glucose preference

(c)

PART (c): CHI-SQUARE CALCULATION

Null Hypothesis: (**1 point**)

The flies will be evenly distributed across the three different parts of the choice chamber.

	Observed (o)	Expected (e)* (**1 point**)	$(o - e)^2/e$
End with ripe banana	45	20	31.25
Middle	3	20	14.45
End with unripe banana	12	20	3.2
Total	60	60	48.9

*Expected values must be those predicted by the null hypothesis provided in the student response, add up to 60, and include no cells equal to 0.

(d)

- Correct explanation with justification of why the stated null hypothesis is rejected or not rejected. Response must clarify each of the following:
  - degrees of freedom (df) = 2 and p = 0.05 (critical value = 5.99)
    OR
    degrees of freedom (df) = 2 and p = 0.01 (critical value = 9.21)
  - how the calculated test statistic compares to the selected critical value
  - whether the null hypothesis should be rejected

(e)

- Stimulus → Response
- Input →(possible integration) →Output

Scoring Statistics	
Mean: 3.63	Standard Deviation: 1.75

2013 #4

Course Content	Practice and Skill
3.4: Photosynthesis 3.4.A: Describe the photosynthetic processes and structural features of the chloroplast that allow organisms to capture and store energy. 3.4.B: Explain how cells capture energy from light and transfer it to biological molecules for storage and use. 8.2: Energy Flow Through Ecosystems 8.2.B: Explain how energy flows and matter cycles through trophic levels.8.2.D: Explain how the activities of autotrophs and heterotrophs enable the flow of energy within an ecosystem.	1.A: Describe biological concepts and processes. 2.A: Describe characteristics of visual representations of biological concepts and processes.

Part	Scoring Guidelines

(a)

Identification: **1 point maximum**

I = photosynthesis / Calvin cycle
AND
II = (cellular) respiration / citric acid cycle / Krebs cycle

Explanation: **1 point each row; 2 points maximum**

Process	Carbon Input	Role of Energy in the Movement of Carbon	Carbon Output
Photosynthesis	CO_2 is fixed	Uses (light) energy OR ATP from light reactions	Organic molecules
(Cellular) Respiration	Organic molecules are hydrolyzed / broken down	Uses energy for cellular processes such as growth and /or ATP production	CO_2

(b)

- Plant
- Algae
- Photosynthetic protist (e.g., Euglena)
- Cyanobacterium
- CO_2 fixing bacterium
- Lichen (not fungus)

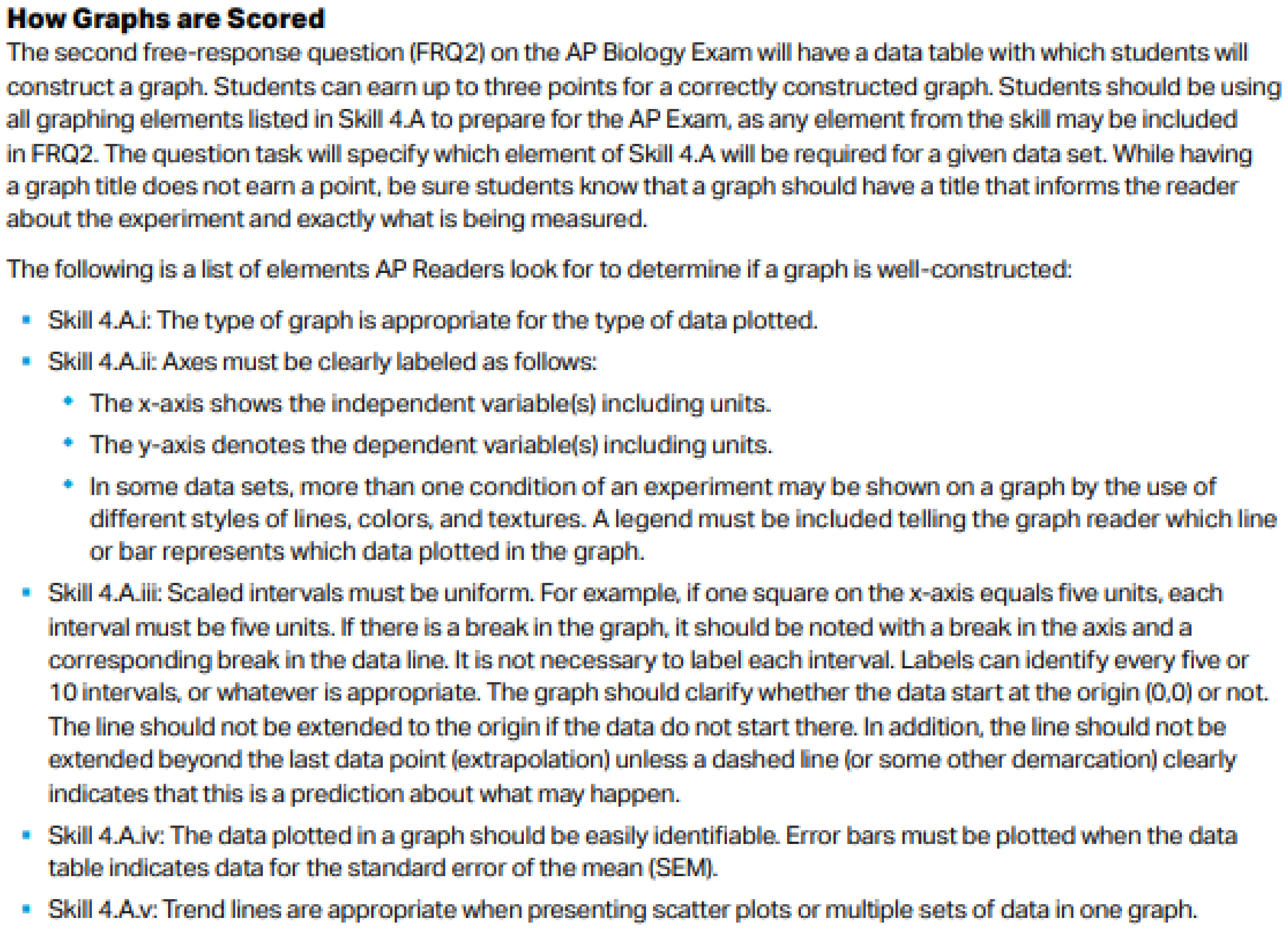
Scoring Statistics	
Mean: 1.64	Standard Deviation: 1.39

Graphing FRQ Practice

Science Practice #4.A:

Construct a graph to represent the data, including: x-y graphs (bar, histogram, line, log scale, dual y), scatter plot, box and whisker plot, and pie chart. The graph should include the following components:

i. type of graph appropriate for the data
ii. axis labeling, including appropriate units and legend
iii. scaling
iv. accurately plotted data (including error bars when appropriate)
v. trend line (when appropriate)



How Graphs are Scored

The second free-response question (FRQ2) on the AP Biology Exam will have a data table with which students will construct a graph. Students can earn up to three points for a correctly constructed graph. Students should be using all graphing elements listed in Skill 4.A to prepare for the AP Exam, as any element from the skill may be included in FRQ2. The question task will specify which element of Skill 4.A will be required for a given data set. While having a graph title does not earn a point, be sure students know that a graph should have a title that informs the reader about the experiment and exactly what is being measured.

The following is a list of elements AP Readers look for to determine if a graph is well-constructed:

- Skill 4.A.i: The type of graph is appropriate for the type of data plotted.
- Skill 4.A.ii: Axes must be clearly labeled as follows:
  - The x-axis shows the independent variable(s) including units.
  - The y-axis denotes the dependent variable(s) including units.
  - In some data sets, more than one condition of an experiment may be shown on a graph by the use of different styles of lines, colors, and textures. A legend must be included telling the graph reader which line or bar represents which data plotted in the graph.
- Skill 4.A.iii: Scaled intervals must be uniform. For example, if one square on the x-axis equals five units, each interval must be five units. If there is a break in the graph, it should be noted with a break in the axis and a corresponding break in the data line. It is not necessary to label each interval. Labels can identify every five or 10 intervals, or whatever is appropriate. The graph should clarify whether the data start at the origin (0,0) or not. The line should not be extended to the origin if the data do not start there. In addition, the line should not be extended beyond the last data point (extrapolation) unless a dashed line (or some other demarcation) clearly indicates that this is a prediction about what may happen.
- Skill 4.A.iv: The data plotted in a graph should be easily identifiable. Error bars must be plotted when the data table indicates data for the standard error of the mean (SEM).
- Skill 4.A.v: Trend lines are appropriate when presenting scatter plots or multiple sets of data in one graph.

(College Board CED 2026 pg 189)

Bar Graphs

Bar graphs are used to visually compare two samples of categorical or discrete data. Bar graphs are also used to visually compare the calculated means with error bars of normal data (Figure 1). Many questions and investigations in biology call for a comparison of populations. If a variable is being measured across multiple groups, the most appropriate way to represent the data is likely a bar graph showing the means of the two samples with standard error indicated. In Figure 1, the sample standard error (also known as the sample error of the sample mean) is indicated by an error bar at the top of each shaded bar.

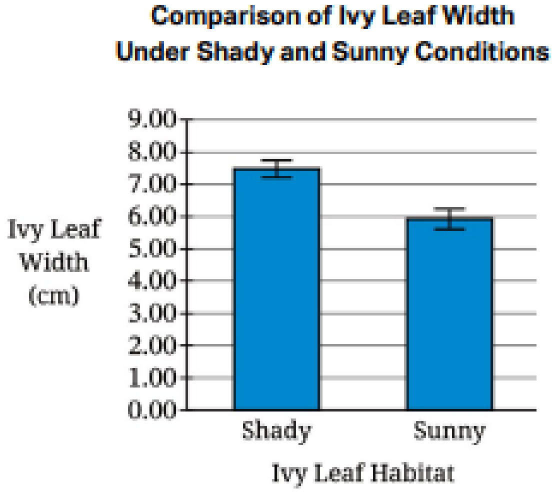


Figure 1. Bar Graph, error bars represent $\pm 2SE_{\overline{x}}$

Histograms

Histograms are used to display the distribution of data, showing the central tendencies and the spread of the data. They are different from bar graphs in that they illustrate ranges or frequencies of data within the bar, whereas bar graphs only show comparisons of categorical data. Additionally, bar graphs compare two variables while histograms show only one variable. Figure 2 is an example of a histogram that consists of uniform range intervals (e.g., 160–199, 200–239) that span the entire range of the data. If enough measurements are made, the data on a histogram can show an approximate normal distribution, or bell-shaped distribution. The normal distribution is very common in biology and is a basis for the predictive power of statistical analysis.

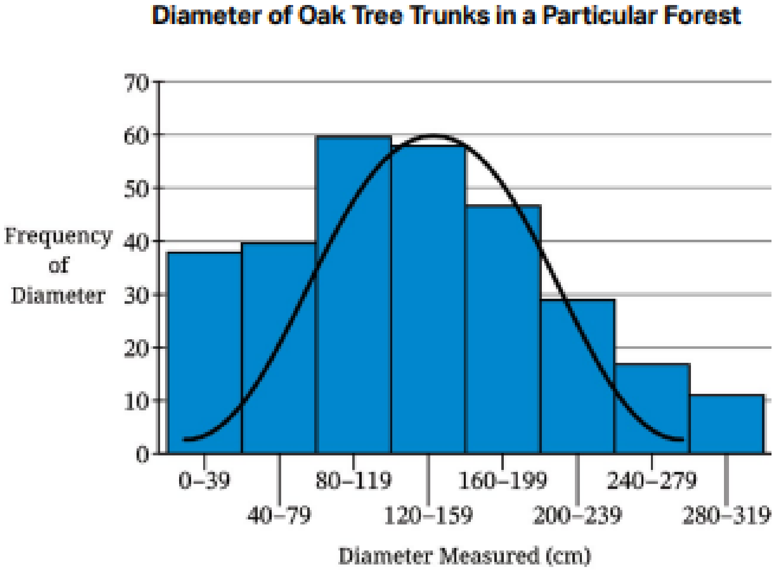


Figure 2. Histogram

(College Board CED 2026 pg. 184)

Line Graphs

Line graphs (Figure 3) are used to track changes over time using a series of continuous data points as opposed to discrete data. Line graphs help to visualize relationships between variables when changes in the dependent variable are tracked over time. Data points should be clearly marked and connected by a line.

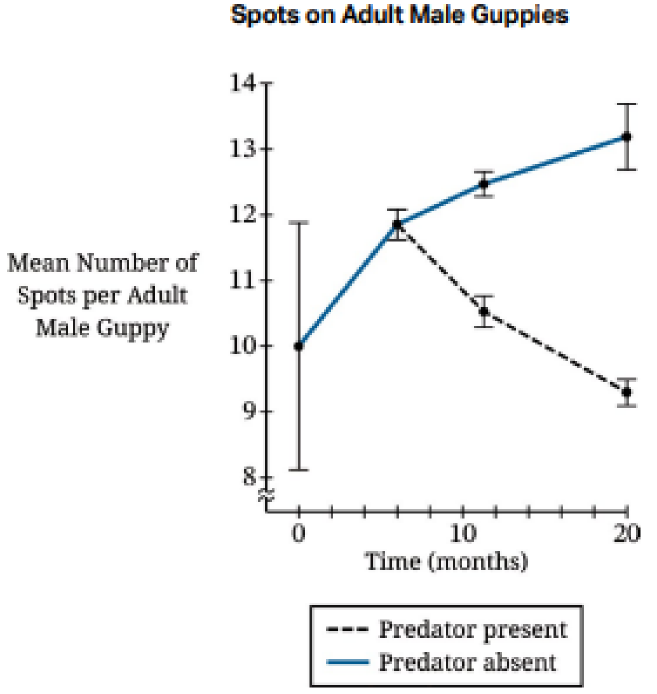


Figure 3. Line Graph (error bars represent ±2$SE_{\bar{x}}$)

Log Scale Graphs

Log scale graphs use a nonlinear scale to plot data that span very large quantities (Figure 4); this helps prevent the axes from being too long for the graph. This type of graph is useful for illustrating the differences between the lowest and highest points in the data.

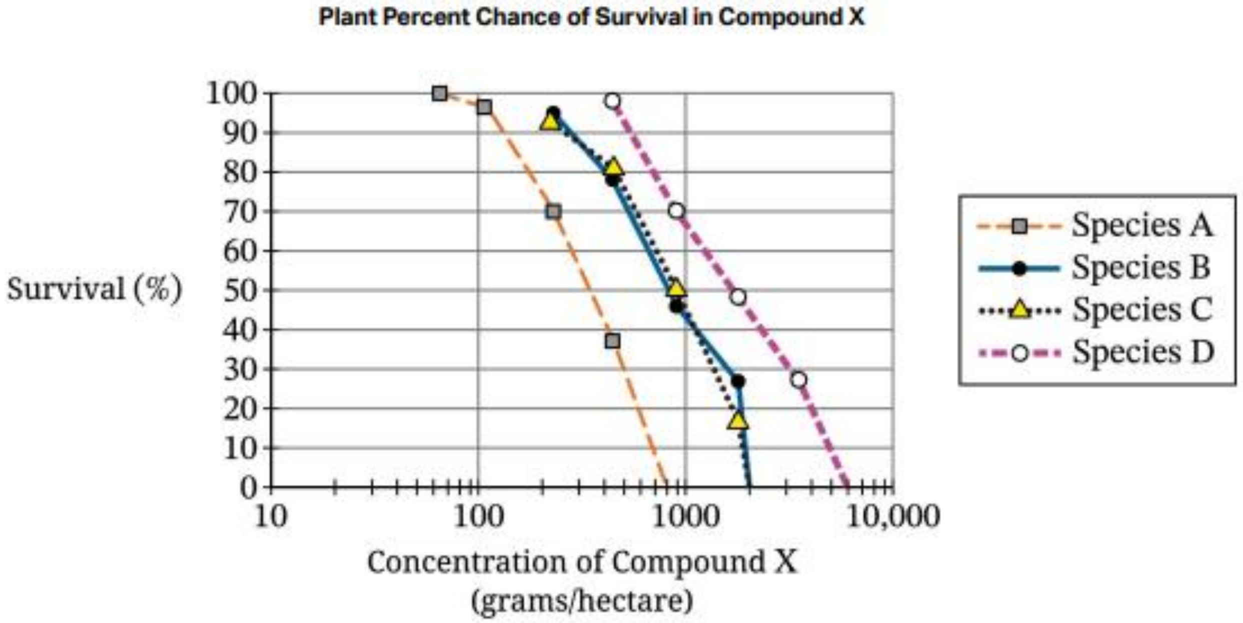


Figure 4. Log Scale Graph

(College Board CED 2026 pg. 185)

Dual y-Axes Graphs

Dual y-axes graphs are used when comparing two datasets that have different units of measurement. Figure 5 is an example of a dual y-axes line graph (note that bar graphs can also have dual y-axes), which shows the proportion of a frog population infected by a parasite and the relative frog population size.

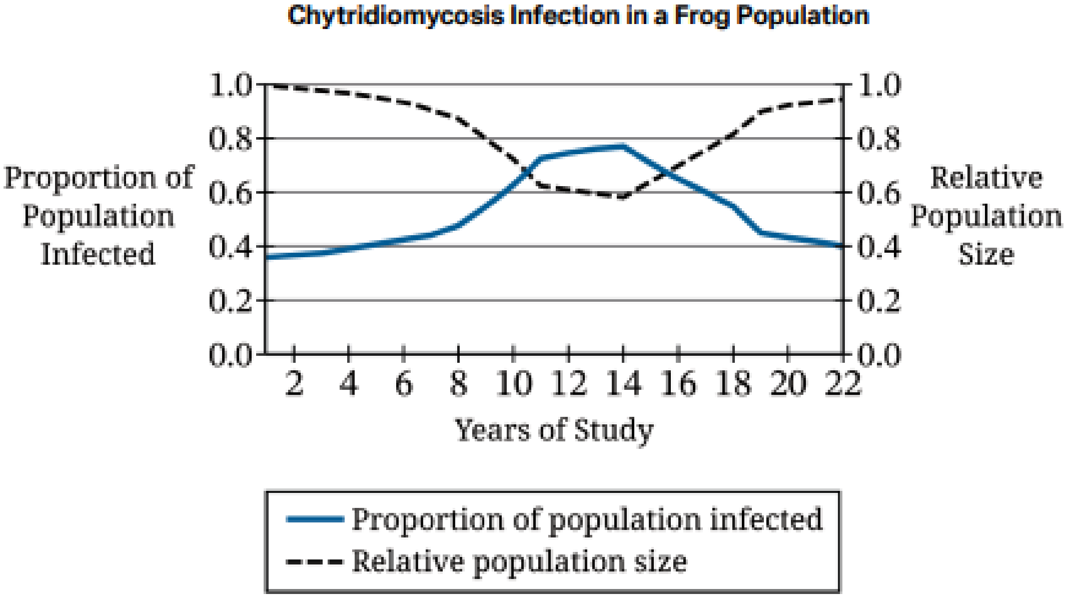


Figure 5. Line Graph with Dual y-Axes

Scatterplots

Scatterplots (Figure 6) are graphs used to visually explore associations between two variables. When comparing one measured variable to another and looking for trends, it is appropriate to plot the individual data points on an *x*-*y* plot, creating a scatterplot. Trend lines show the general direction (increase or decrease) in the overall data trends and can be estimated or calculated. Scatterplots can also be used to plot a manipulated independent *x*-variable against the dependent *y*-variable.

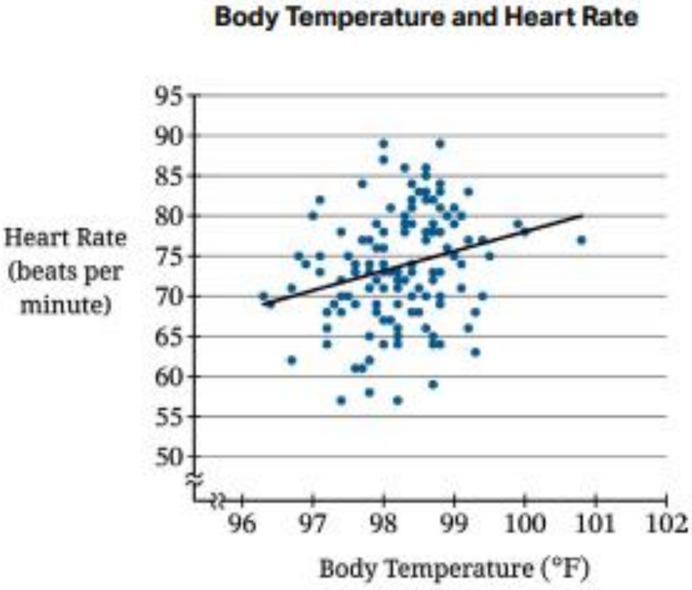


Figure 6. Scatterplot with a Trend Line

(College Board CED 2026 pg. 186)

Box and Whisker Plots

Box and whisker plots allow graphical comparison of two samples of data. Figure 7 shows plotted data from Table 1. Box and whisker plots illustrate the medians and quartiles as well as the minimum and maximum data points. In the graph, the tops and bottoms of the vertical lines show the maximum and minimum values in the dataset, respectively (these are known as the whiskers). The whiskers are commonly mistaken for error bars. The top of each box shows the upper quartile, the bottom of each box shows the lower quartile, and the horizontal line within each box represents the median. The graph allows the investigator to determine at a glance, in this case, that the ash leaves appear to decay the fastest and the beech leaves take the longest to decay.

Table 1. Leaf Decay in Different Tree Species

Bag	Percent Decay per Bag		
Number	Ash	Sycamore	Beech
1	51	40	34
2	63	33	15
3	44		26
4		52	21
5	48	48	
6	32	35	11
7	70	44	19
8	48	63	32
9	57	40	

Comparison of Leaf Decay in Different Tree Species

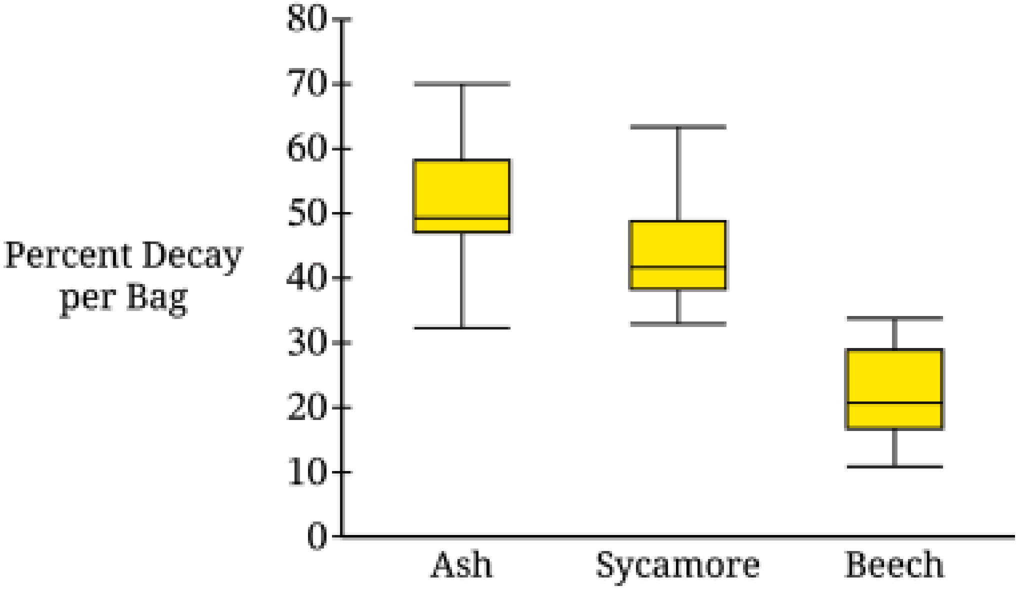


Figure 7. Box and Whisker Plot

(College Board CED 2026 pg. 187)

Pie Charts

Pie charts are used for comparing different parts of a whole or percentages (Figure 8 and Figure 9). The segments in a pie chart should be representative of that part's proportion in relation to the full dataset being displayed.

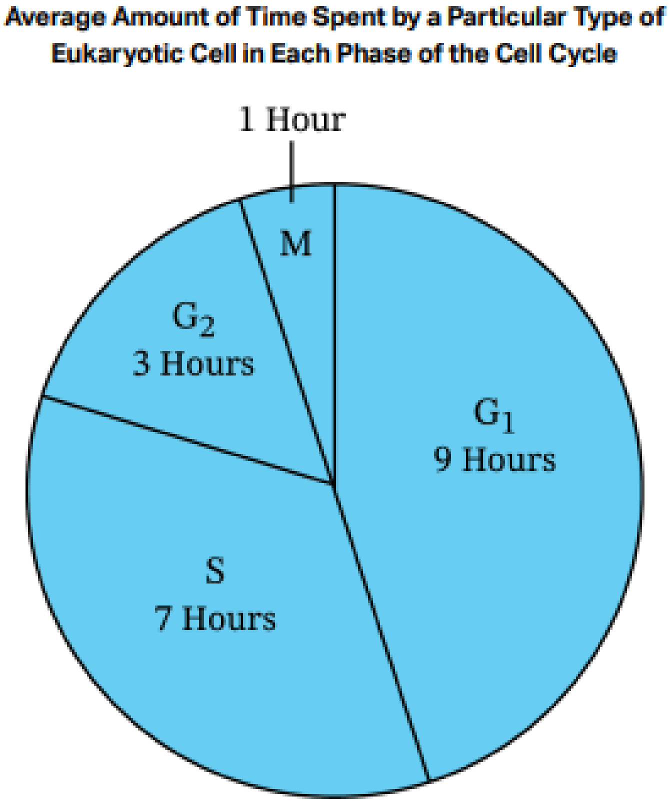


Figure 8. Cell Cycle Pie Chart

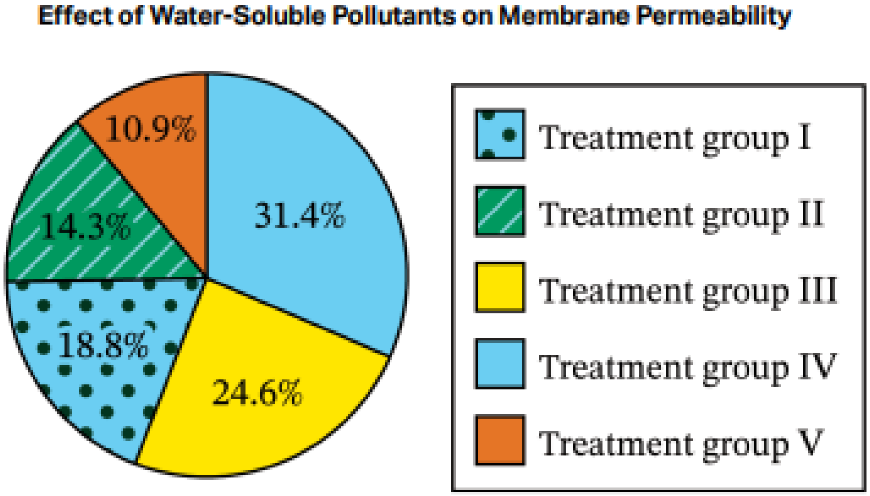


Figure 9. Water Soluble Pollutants Pie Chart

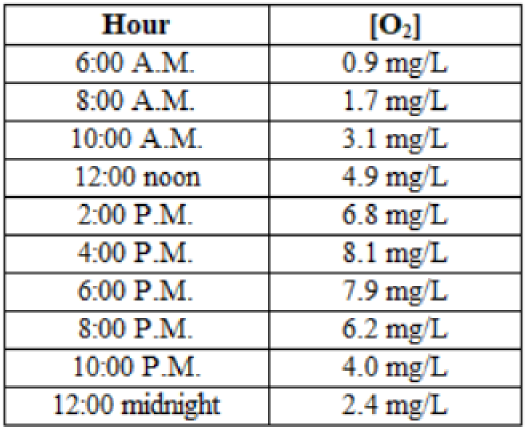
(College Board CED 2026 pg. 188)

Graphing FRQ Practice

To provide you specific practice with graphing, I have compiled just the graphing components from the 1999 – 2019, 2021 - 2025 FRQs. The questions from 2013 – 2019, 2021 – 2025 might be repeats as they could have been used in the unit specific FRQ sections.

2001 #3a

A biologist measured dissolved oxygen in the top 30 centimeters of a moderately eutrophic (mesotrophic) lake in the temperate zone. The day was bright and sunny, and the wind was calm. The results of the observations are presented below.



Hour	**[O_2]**
6:00 A.M.	0.9 mg/L
8:00 A.M.	1.7 mg/L
10:00 A.M.	3.1 mg/L
12:00 noon	4.9 mg/L
2:00 P.M.	6.8 mg/L
4:00 P.M.	8.1 mg/L
6:00 P.M.	7.9 mg/L
8:00 P.M.	6.2 mg/L
10:00 P.M.	4.0 mg/L
12:00 midnight	2.4 mg/L

(a) Using the graph paper provided, **plot** the resultat were obtained. Then, using the same set of axes, **draw** and **label** an additional line/curve representing the results that you would predict had the day been heavily overcast.

2002 #4a, b

The following experiment was designed to test whether different concentration gradients affect the rate of diffusion. In this experiment, four solutions (0% NaCl, 1% NaCl, 5% NaCl, and 10% NaCl) were tested under identical conditions. Fifteen milliliters (mL) of 0% NaCl were put into a bag formed of dialysis tubing that is permeable to Na^+, Cl^-, and water. The same was done for each NaCl solution. Each bag was submerged in a separate beaker containing 300 mL of distilled water. The concentration of NaCl in mg/L in the water outside each bag was measured at 40-second intervals. The results from the 5% bag are shown in the table below.

CONCENTRATION IN mg/L OF NaCl OUTSIDE THE 5% NaCl BAG

Time (seconds)	NaCl (mg/L)
0	0
40	130
80	220
120	320
160	400

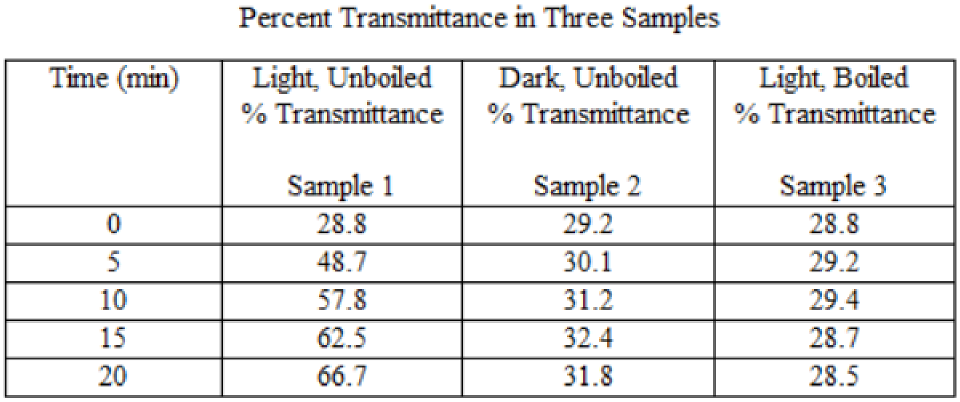
(a) On the axes provided, **graph** the data for the 5% NaCl solution.

(b) Using the same set of axes, **draw** and **label** three additional lines representing the results that you would predict for the 0% NaCl, 1% NaCl, and 10% NaCl. Explain your predictions.

2004 #3a

A controlled experiment was conducted to analyze the effects of darkness and boiling on the photosynthetic rate of incubated chloroplast suspensions. The dye reduction technique was used. Each chloroplast suspension was mixed with DPIP, an electron acceptor the changes from blue to clear when it is reduced. Each sample was placed individually in a spectrophotometer and the percent transmittance was recorded. The three samples used were prepared as follows.

- Sample 1 - chloroplast suspension + DPIP
- Sample 2 - chloroplast suspension surrounded by foil wrap to provide a dark environment + DPIP
- Sample 3 - chloroplast suspension that has been boiled + DPIP



Percent Transmittance in Three Samples

Time (min)	Light, Unboiled % Transmittance Sample 1	Dark, Unboiled % Transmittance Sample 2	Light, Boiled % Transmittance Sample 3
0	28.8	29.2	28.8
5	48.7	30.1	29.2
10	57.8	31.2	29.4
15	62.5	32.4	28.7
20	66.7	31.8	28.5

(a) On the axes provided, **construct** and **label** a graph showing the results for the three samples.

2005 #1a

Yeast cells are placed in an apparatus with a solution of sugar (a major nutrient for yeast metabolism). The apparatus detects bubbles of gas released by the yeast cells. The rate of respiration varies with the surrounding temperatures as indicated by the data below.

Temperature (°C)	0	10	20	30	40	50	60	70
Number of bubbles of gas produced per minute	0	3	7	12	7	4	1	0

(a) **Graph** the results on the axes provided. **Determine** the optimum temperature for respiration in the yeast.

2005(B) #4a

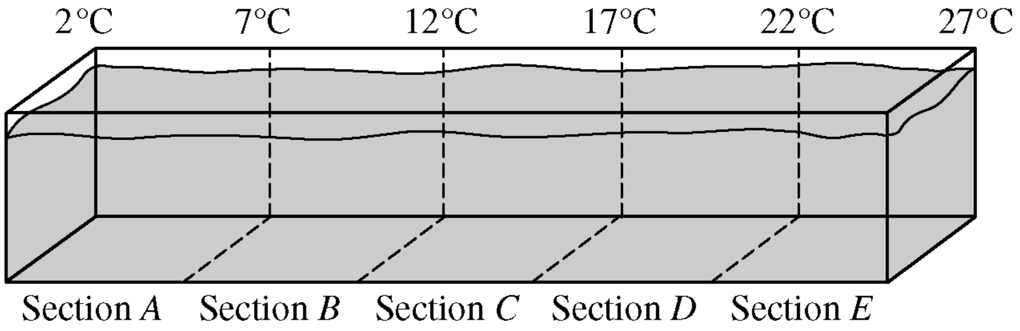
Water potential in potato cells was determined in the following manner. The initial masses of six groups of potato cores were measured. The potato cores were measured. The potato cores were placed in sucrose solution of various molarities. The masses of the cores were measured again after 24 hours. Percent changes in mass were calculated. The results are shown below.

Molarity of Sucrose in Beakers	Percent Change in Mass
0.0 M	18.0
0.2	5.0
0.4	- 8.0
0.6	- 16.0
0.8	- 23.5
1.0	- 24.0

(a) **Graph** these data on the axes provided. From your graph, **find** the apparent molar concentration (osmolarity) of the potato core cells.

2009 #1a

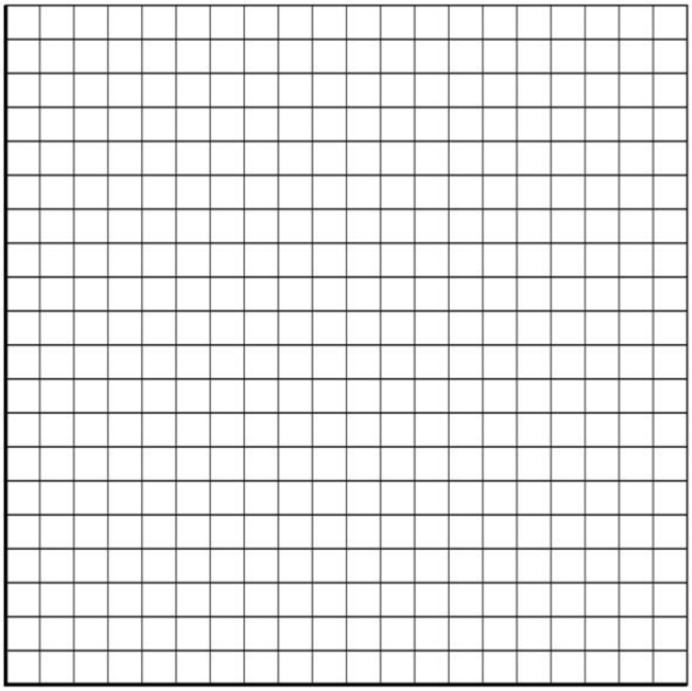
An experiment on a species of small freshwater fish recorded their behavioral responses to different temperatures. Ten fish were each tested once, one at a time.



To begin the experiment, a fish was removed from a stock tank (maintained at 22°C) and placed in the temperature-gradient tank drawn below. After the fish had spent 30 minutes in the temperature-gradient tank, the section where the fish was located was recorded. Additional observations were recorded every 5 minutes, for a total of 7 observations per fish. A summary of the combined data for all 10 fish appears below.

Section	Fish/Section
A	9
B	11
C	34
D	12
E	4

(a) On the axes provided, **construct** the appropriate type of labeled graph showing the relationship between water temperature and fish distribution. **Summarize** the outcome of the experiment.



2010 #2a

An experiment was conducted to measure the reaction rate of the human salivary enzyme a-amylase. Ten mL of a concentrated starch solution and 1.0 mL of a-amylase solution were placed in a test tube. The test tube was inverted several times to mix the solution and then incubated at 25°C. The amount of product (maltose) present was measured every 10 minutes for an hour. The results are given in the table below.

Time (minutes)	**Maltose Concentration (μM)**
0	0
10	5.1
20	8.6
30	10.4
40	11.1
50	11.2
60	11.5

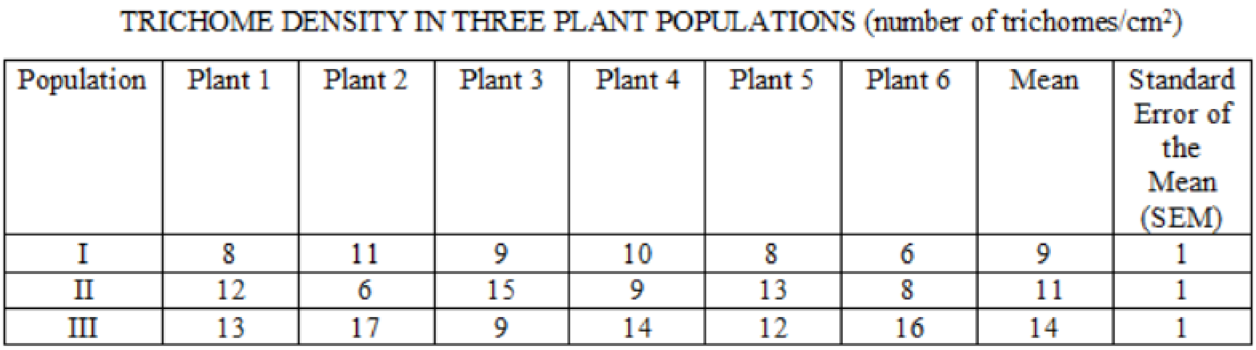
(a) **Graph** the data on the axes provided and **calculate** the rate of the reaction for the time period 0 to 30 minutes.

(c)	**Draw** and **label** another line on the graph to predict the results if the concentration of a-amylase was doubled. **Explain** your predicted results.

2014 #1a

Trichomes are hairlike outgrowths of the epidermis of plants that are thought to provide protection against being eaten by herbivores (herbivory). In a certain plant species, stem trichome density is genetically determined.

To investigate variation in stem trichome density within the plant species, a student counted the number of trichomes on the stems of six plants in each of three different populations. The student used the data to calculate the mean trichome density (numbers of hairs per square centimeter) for each population. The results are provided in the table below.



TRICHOME DENSITY IN THREE PLANT POPULATIONS (number of trichomes/cm^2)

Population	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	Mean	Standard Error of the Mean (SEM)
I	8	11	9	10	8	6	9	1
II	12	6	15	9	13	8	11	1
III	13	17	9	14	12	16	14	1

(a)	On the axes provided, **create** an appropriately labeled graph to illustrate the sample means of the three populations to within 95% confidence (i.e., sample mean ± 2 SEM).

2016 #1a

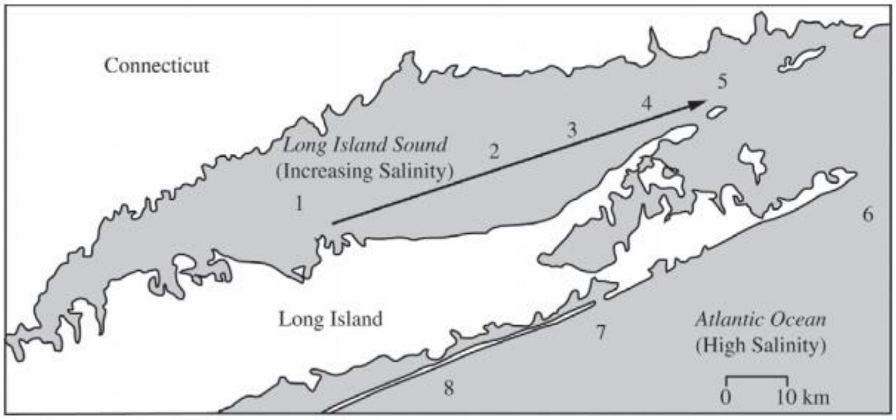

Connecticut
Long Island Sound
(Increasing Salinity)
1
2
3
4
5
6
7
8
Long Island
Atlantic Ocean
(High Salinity)
0
10 km

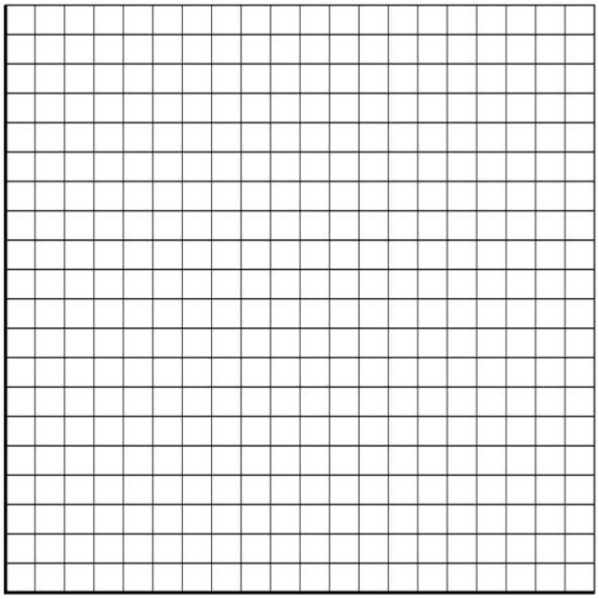
Figure 1. Sampling sites of marine mussels at various locations (1–8) in Long Island Sound and the Atlantic Ocean

TABLE 1. PERCENT OF INDIVIDUALS POSSESSING *lap*^{94} ALLELE

	Long Island Sound					Atlantic Ocean		
Site	1	2	3	4	5	6	7	8
lap^{94} frequency (%)	13	16	25	37	55	59	59	59
Salinity	Low	⟶			High	High		

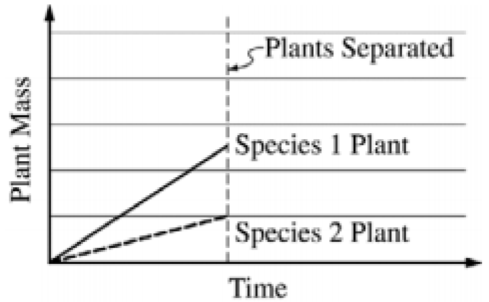
Leucine aminopeptidase (LAPs) are found in all living organisms and have been associated with the response of the marine mussel, *Mytilus edulis*, to changes in salinity. LAPs are enzymes that remove N-terminal amino acids from proteins and release the free amino acids into the cytosol. To investigate the evolution of LAPs in wild populations of *M. edulis*, researchers sampled adult mussels from several different locations along a part of the northeast coast of the United States, as shown in Figure 1. The researchers then determined the percent of individuals possessing a particular *lap* allele, *lap*^{94}, in mussels from each sample site (table 1).

(a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the *lap*^{94} allele in the study population.

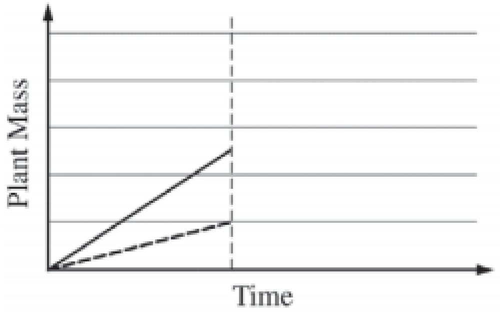


2016 #5

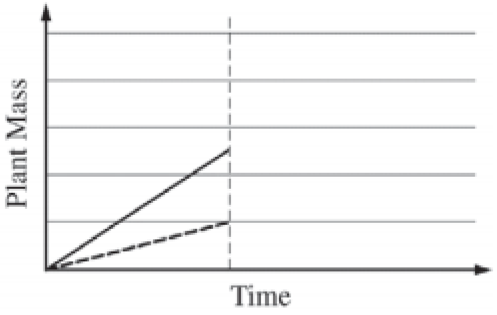
(a) The graph below shows the mass of plants from two different species over time. The plants grew while attached to each other. The plants were separated at the time indicated by the vertical line in the graph.



Using template 1, **graph** the predicted shape of the plant-mass lines after separation of the two plants if the plants were in an obligate mutualistic relationship. On template 2, **graph** the predicted shape of the plant-mass lines if the species 2 plant was a parasite of the species 1 plant. **Justify** each of your predictions.



TEMPLATE 1: OBLIGATE MUTUALISM



TEMPLATE 2: PARASITISM

2017 #1a

In flowering plants, pollination is a process that leads to the fertilization of an egg and the production of seeds. Some flowers attract pollinators, such as bees, using visual and chemical cues. When a bee visits a flower, in addition to transferring pollen, the bee can take nectar from the flower and use it to make honey for the colony.

Nectar contains sugar, but certain plants also produce caffeine in the nectar. Caffeine is a bitter-tasting compound that can be toxic to insects at high concentrations. To investigate the role of caffeine in nectar, a group of researchers studied the effect of 0.1 mM caffeine on bee behavior. The results of an experiment to test the effect of caffeine on bees' memory of a nectar source are shown in Table 1.

TABLE 1. EFFECT OF 0.1 mM CAFFEINE ON MEMORY IN BEES

Treatment	Memory (average probability of revisiting a nectar source $\pm 2SE_{\bar{x}}$)	
	10 Minutes	24 Hours
Control	0.72 ± 0.09	0.41 ± 0.07
Caffeine	0.83 ± 0.07	0.78 ± 0.08

(a) On the axes provided, **construct** an appropriately labeled graph to illustrate the effect of caffeine on the probability of bees revisiting a nectar source (memory).

2019 #2a

A student studying two different aquatic, plant-eating, unicellular protist species (species A and B) designed an experiment to investigate the ecological relationship between the two species (Table 1).

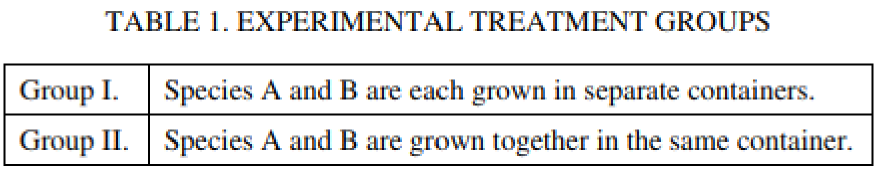


TABLE 1. EXPERIMENTAL TREATMENT GROUPS

Group I.	Species A and B are each grown in separate containers.
Group II.	Species A and B are grown together in the same container.

On In treatment group I, the student placed 10 individuals of species A into a container with liquid growth medium and 10 individuals of species B into a separate container with an equal amount of the same liquid growth medium. In treatment group II, the student placed 5 individuals of each species into a single container with the liquid growth medium. The student then maintained the containers under the same environmental conditions and recorded the number of individuals in each population at various time points. The results are shown in Table 2.

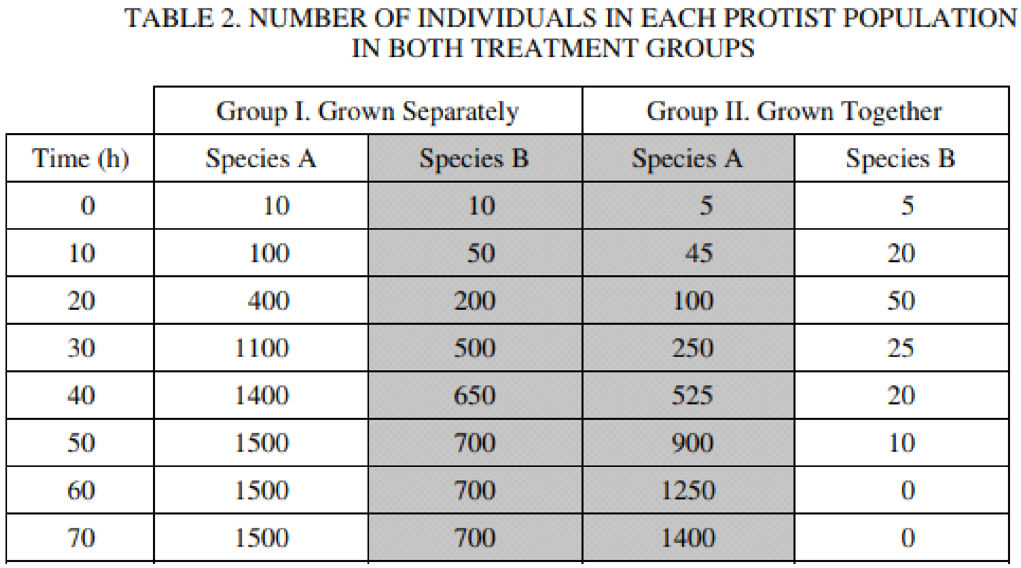
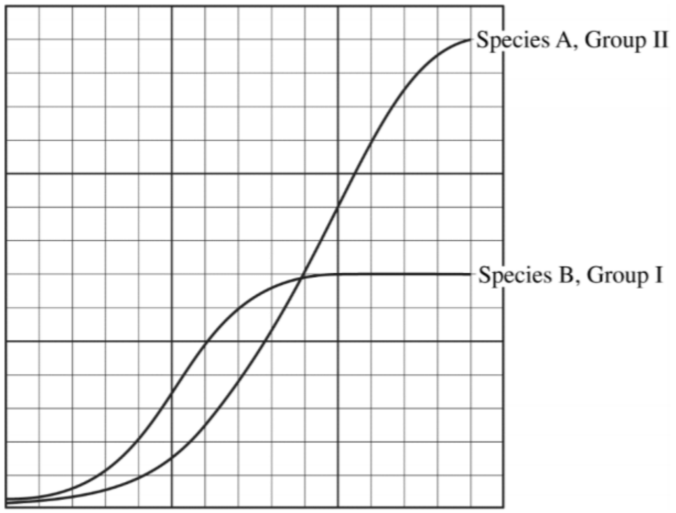


TABLE 2. NUMBER OF INDIVIDUALS IN EACH PROTIST POPULATION IN BOTH TREATMENT GROUPS

	Group I. Grown Separately		Group II. Grown Together	
Time (h)	Species A	Species B	Species A	Species B
0	10	10	5	5
10	100	50	45	20
20	400	200	100	50
30	1100	500	250	25
40	1400	650	525	20
50	1500	700	900	10
60	1500	700	1250	0
70	1500	700	1400	0

(a) The growth curves for species B in group I and for species A in group II (shaded columns) have been plotted on the template. Use the template to **complete** an appropriately labeled line graph to illustrate the growth of species A in treatment group I and species B in treatment group II (unshaded columns).



2021 #2b

Geneticists investigated the mode of inheritance of a rare disorder that alters glucose metabolism and first shows symptoms in adulthood. The geneticists studied a family in which some individuals of generations II and III are known to have the disorder. Based on the pedigree (Figure 1), the geneticists concluded that the disorder arose in individuals II-2 and was caused by a mutation in mitochondrial DNA.

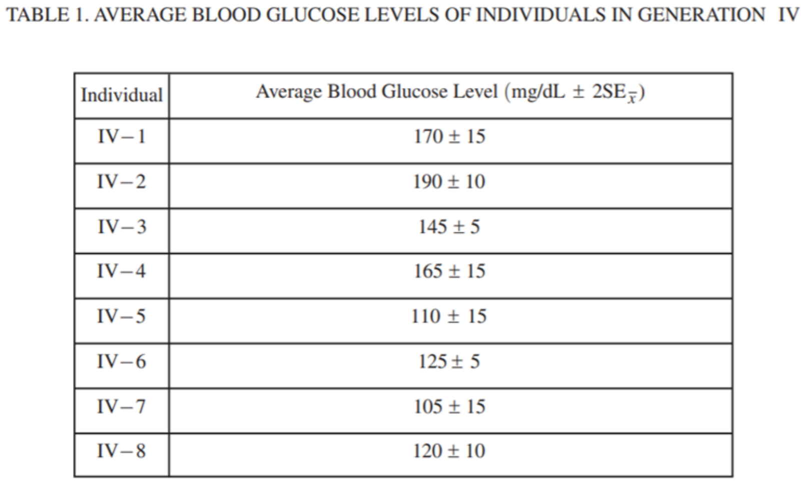


TABLE 1. AVERAGE BLOOD GLUCOSE LEVELS OF INDIVIDUALS IN GENERATION IV

Individual	Average Blood Glucose Level (mg/dL ± $2SE_{\bar{x}}$)
IV – 1	170 ± 15
IV – 2	190 ± 10
IV – 3	145 ± 5
IV – 4	165 ± 15
IV – 5	110 ± 15
IV – 6	125 ± 5
IV – 7	105 ± 15
IV – 8	120 ± 10

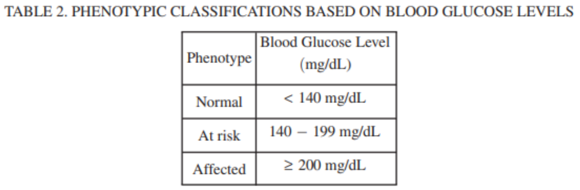
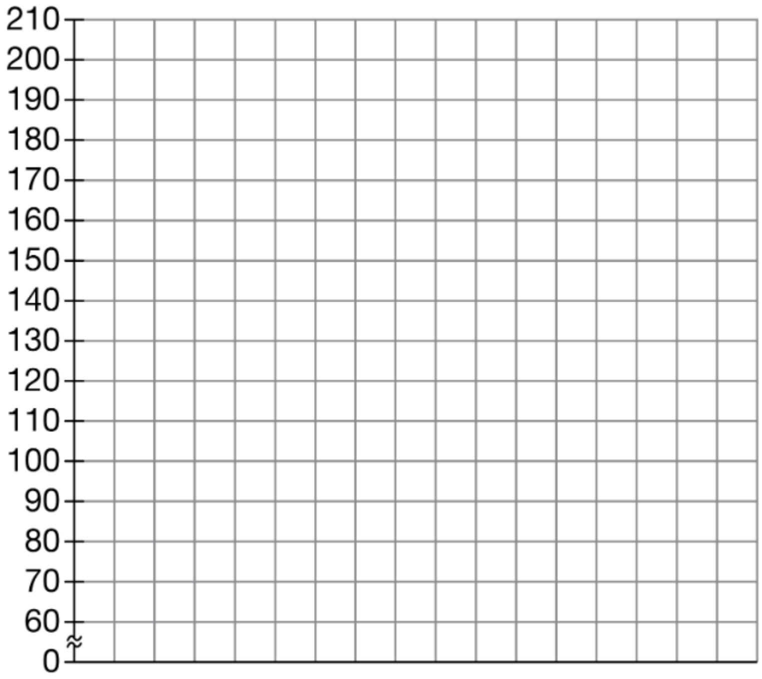


TABLE 2. PHENOTYPIC CLASSIFICATIONS BASED ON BLOOD GLUCOSE LEVELS

Phenotype	Blood Glucose Level (mg/dL)
Normal	< 140 mg/dL
At risk	140 – 199 mg/dL
Affected	≥ 200 mg/dL

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph based on the data in Table 1. **Determine** one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV-1.



2022 #2b

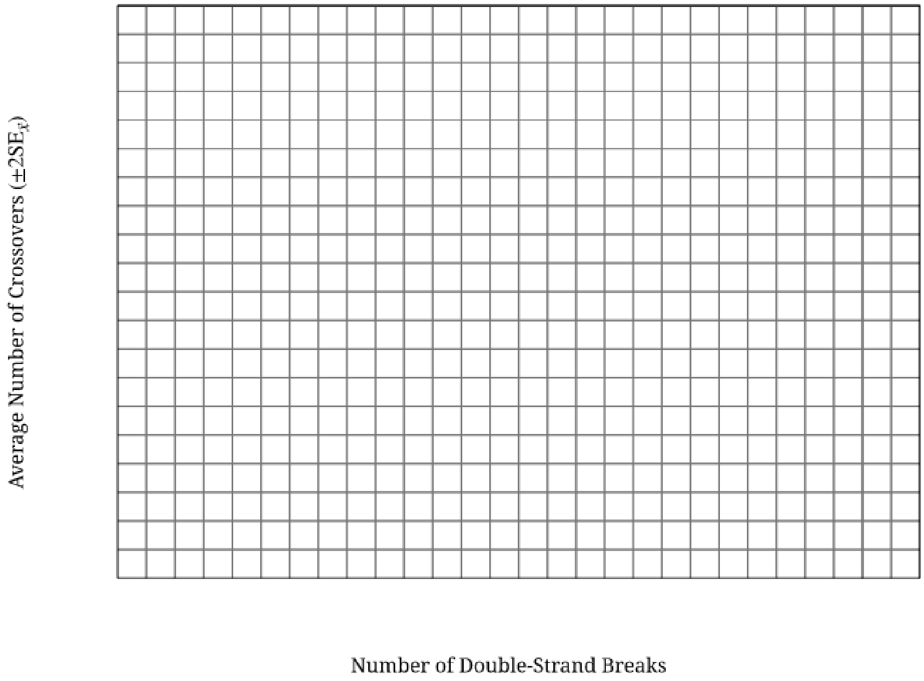
During meiosis, double-strand breaks occur in chromatids. The breaks are either repaired by the exchange of genetic material between homologous nonsister chromatids, which is the process known as crossing over (Figure 1A), or they are simply repaired without any crossing over. Plant breeders developing new varieties of corn are interested in determining whether, in corn, a correlation exists between the number of meiotic double-strand chromatid breaks and the number of crossovers.

Using specialized staining and microscopy techniques, scientists counted the number of double-strand chromatid breaks and the number of crossovers in the same number of meiotic gamete-forming cells of six inbred strains of corn (Table 1).

TABLE 1. NUMBER OF CHROMATID DOUBLE-STRAND BREAKS AND AVERAGE NUMBER OF CROSSOVERS IN INBRED STRAINS OF CORN

Strain of Corn	Number of Double-Strand Breaks	Average Number of Crossovers ($\pm 2SE_{\bar{x}}$)
I	710	19.5 ± 0.5
II	650	18.0 ± 0.7
III	600	17.5 ± 1.0
IV	510	16.0 ± 1.0
V	425	14.0 ± 0.5
VI	325	11.0 ± 1.5

Using the template in the space provided for your response, construct an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. Based on the data, determine whether corn strains I, II, and III differ in their average number of crossovers.



2023 #2b, c

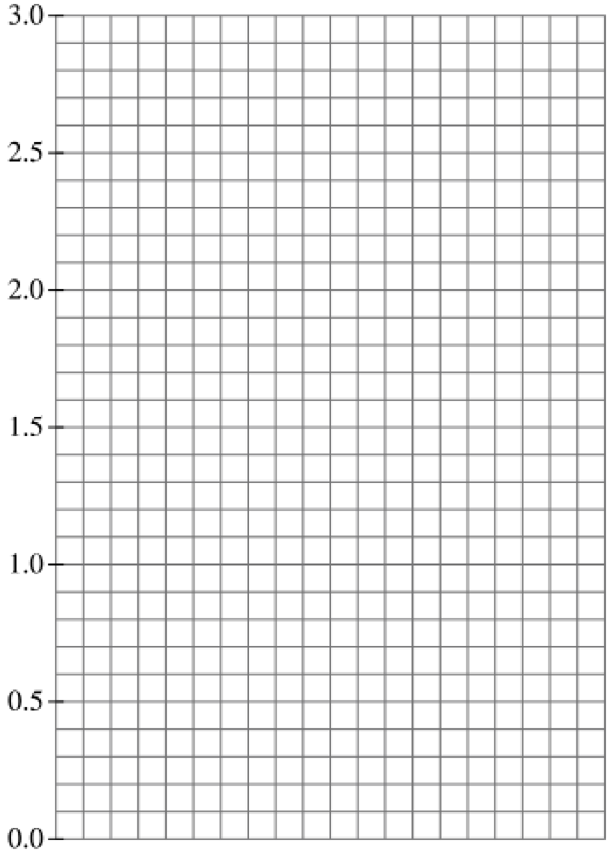
Elevated levels of CO_2 increase the rate of photosynthesis and growth in plants. Scientists studying the mechanisms involved in these increases examined a variety of species and found that when plants are exposed to elevated levels of CO_2, there is an increase in the number of chloroplasts per cell. To investigate whether the elevated levels of CO_2 have a similar effect on the number of mitochondria in plant cells, the scientists then selected six of these species to quantify the number of mitochondria per cell when the plants were exposed to both normal and elevated levels of CO_2 (Table 1).

TABLE 1. AVERAGE NUMBER OF MITOCHONDRIA IN PLANTS EXPOSED TO NORMAL AND ELEVATED LEVELS OF CO_2

Species	Mitochondria at Normal CO_2 (per 100 μm^2 of cell area) $\pm 2SE_{\bar{x}}$	Mitochondria at Elevated CO_2 (per 100 μm^2 of cell area) $\pm 2SE_{\bar{x}}$
1	1.0 ± 0.10	1.6 ± 0.10
2	0.4 ± 0.05	0.9 ± 0.08
3	0.5 ± 0.07	0.9 ± 0.10
4	0.3 ± 0.03	0.6 ± 0.06
5	0.7 ± 0.06	1.5 ± 0.22
6	1.3 ± 0.15	2.4 ± 0.22

(b) Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2.

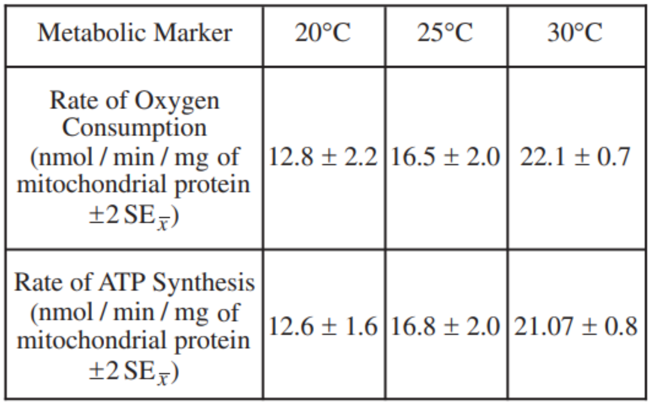
(c) Based on the data in Table 1, ***describe*** the relationship between the level of CO_2 and the average number of mitochondria per unit area of a cell.



2024 #2 b, c

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES



Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

b)

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data shown in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data provided, **determine** the temperature in °C at which the rate of oxygen consumption is different from the rate of oxygen consumption at 25 C° .

c) Based on the data in Table 1, describe the effect of temperature on the rate of ATP synthesis in liver cells from toads.

2025 #2

Many insects rely on pheromones (chemical signals) that are released by the females to find mating partners. Scientists hypothesize that, in a certain type of moth, the behavior of male moths in response to pheromones is regulated by the extracellular signaling molecule 20E.

To investigate whether the binding of 20E to its receptor, DopEcR, affects behavior in moths, scientists injected male moths with saline (control solution) or with small interfering RNA molecules (siRNAs) that inhibit the expression of the gene encoding DopEcR. The scientists then exposed the moths to the pheromone and determined the percent of total time observed that the moths engaged in general activity, defined as movement in any direction. The scientists also determined the percent of the general activity time that the moths spent in oriented activity, defined as movement toward an area of high pheromone concentration (Table 1).

Table 1. Average General and Oriented Activity in Male Moths Injected With Saline or siRNA Molecules

Treatment	General Activity (percent of total time observed, average $\pm 2SE_{\bar{x}}$)	Oriented Activity (percent of general activity, average $\pm 2SE_{\bar{x}}$)
Male moths injected with saline (control solution)	95 ± 5	60 ± 4
Male moths injected with siRNAs that inhibit expression of the gene encoding DopEcR	90 ± 8	25 ± 6

(b)

i. Using the template in the space provided for your response, **construct** an appropriate type of graph that represents the data in Table 1. Your graph should be appropriately plotted and labeled.

ii. Based on the data in Table 1, **determine** the type of activity that was affected by inhibiting the expression of the DopEcR receptor.

(c)

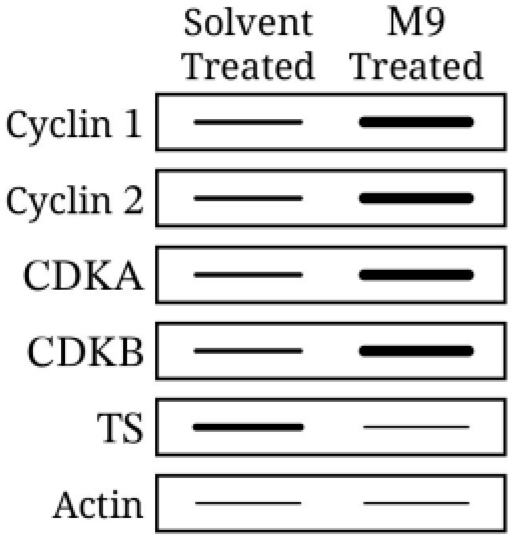
i. Based on Table 1, **identify** the treatment group in which the oriented activity was greater than 50% of the general activity.

2026 CED Q2

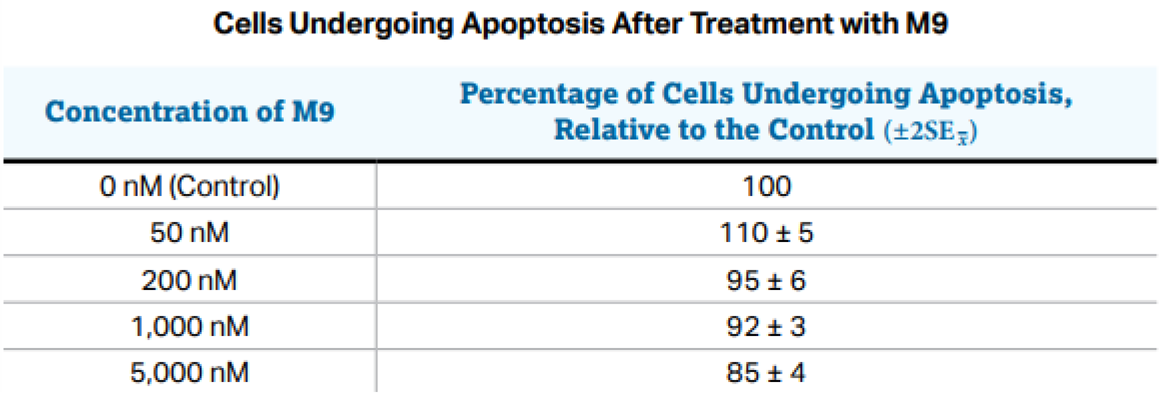
RH is a hormone that binds to the RH receptor in the plasma membrane and affects cell division. Researchers studying cancer have identified a chemical, M9, that performs the same role as RH, and they were interested in the effect of M9 on the growth of cancer cells.

In the first experiment, the researchers treated cancer cells growing in a petri dish with either solvent alone or solvent and M9. They used gel electrophoresis to determine the effect of M9 on the production of six proteins. The six proteins include two cyclin proteins (cyclin 1 and cyclin 2), two cyclin-dependent kinases (CDKA and CDKB), the tumor suppressor protein TS, and actin, a protein typically expressed equally in all cells. The thickness of the line in the figure indicates a higher concentration of protein.

Relative Amounts of Six Proteins in Cancer Cells Treated with Solvent Alone or Solvent and M9



In the second experiment, the researchers investigated the effect of M9 on apoptosis. They incubated cancer cells with solvent alone or with increasing concentrations of M9 and then determined the percentage of cells undergoing apoptosis in each treatment group relative to the control as shown in the table.



Cells Undergoing Apoptosis After Treatment with M9

Concentration of M9	Percentage of Cells Undergoing Apoptosis, Relative to the Control (±2SE$_{\bar{x}}$)
0 nM (Control)	100
50 nM	110 ± 5
200 nM	95 ± 6
1,000 nM	92 ± 3
5,000 nM	85 ± 4

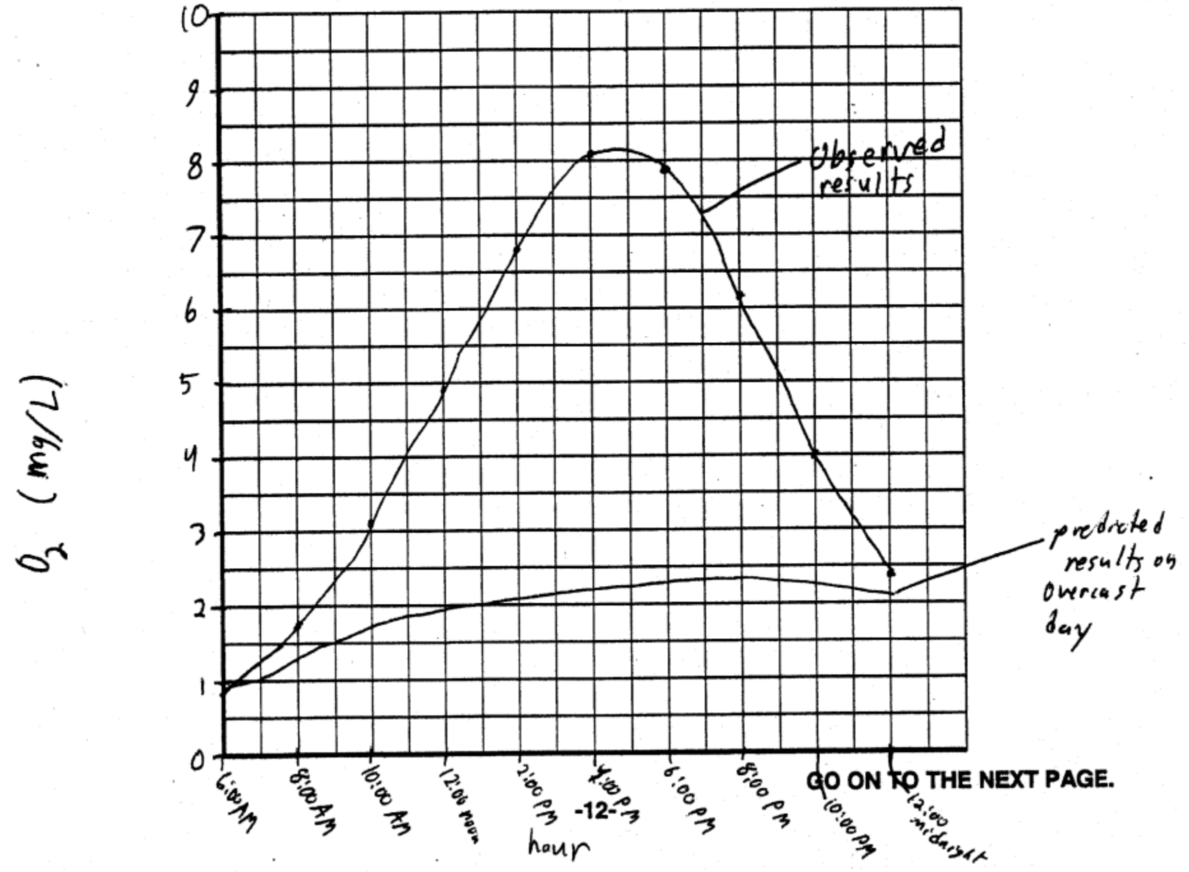
Part B:

i. Using the template in the space provided for your response, **construct** a bar graph that represents the data in the table. Your graph should be appropriately plotted and labeled.

ii. Based on the data in the table, **determine** which two M9 concentrations are statistically similar to one another.

Graphing FRQ Practice - KEY

The following graphs are from the exemplar responses on AP Central for the question and the scoring guidelines.

2001 #3a	
(a)	

4 points possible

1 point for proper orientation of graph (independent variable on x-axis)

1 point for graph (all of the elements below must be present)

- Uniform spacing of units
- Correct labeling of axes
    - proper numbering (a minor error acceptable)
    - X-axis label: “Time”/ “Hour”/a.m., p.m. labels/a conversion to integers requires unit label as well
    - Y-axis: oxygen label **and** mg/L Unit

1 point for correct plot of data points

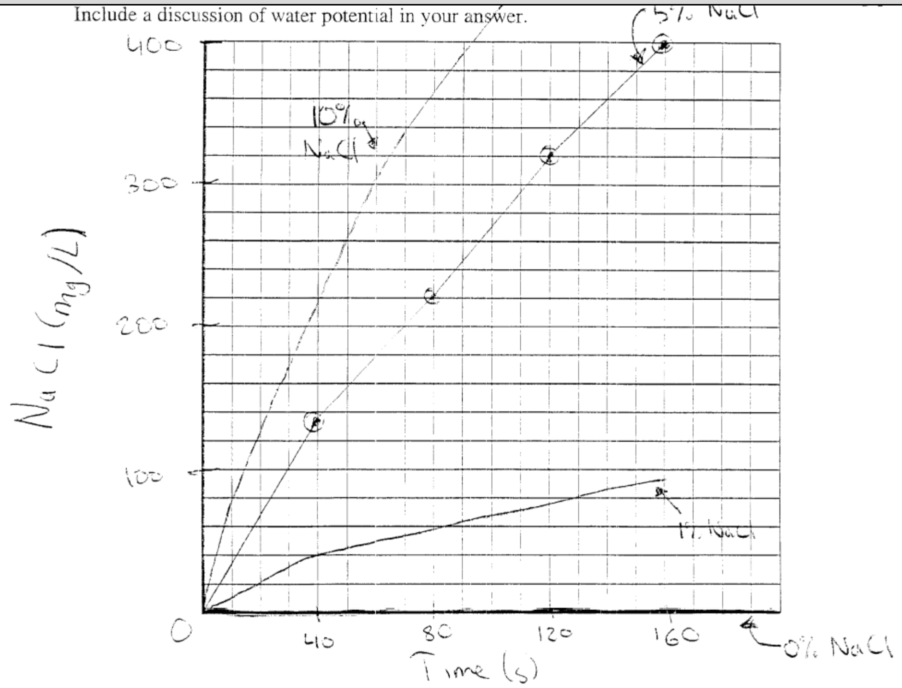
- No connecting line necessary
- No point if more than one data point is misplotted
- No point if there is a **solid** extrapolation line beyond the 6:00 a.m. data point to the origin **or** the 12 midnight data point

1 point for drawing the cloudy day prediction Line/Curve (all of the elements below must be present)

- Distinguish between the two curves with a legend or direct labeling of one curve
- Position completely under the bright-day curve (may touch toward the tails)
- There must be some curve to the line (no flat lines)

2002 #4a, b

Include a discussion of water potential in your answer.



3 points maximum

1 point correct orientation with dependent variable (concentration) on y (vertical) axis and independent variable (time) on x (horizontal) axis

1 point correct axes labels with units **and** scaling for 5% line on axes provided

1 point correct plotting of all data points including zero (0,0); line is not necessary but if drawn must not extend beyond last data point; dashing line beyond last data point is okay; arrow at end of line is okay

4 points maximum

1 point correct prediction and legend (or label) for 0%, 1%, **and** 10% lines (0% line flat, 1% line below 5% line, 10% line above 5% line)

Explanation points

1 point correct explanation for 0% line (e.g., since there is no NaCl in the bag no Na^+Cl^- can diffuse into the water in the beaker)

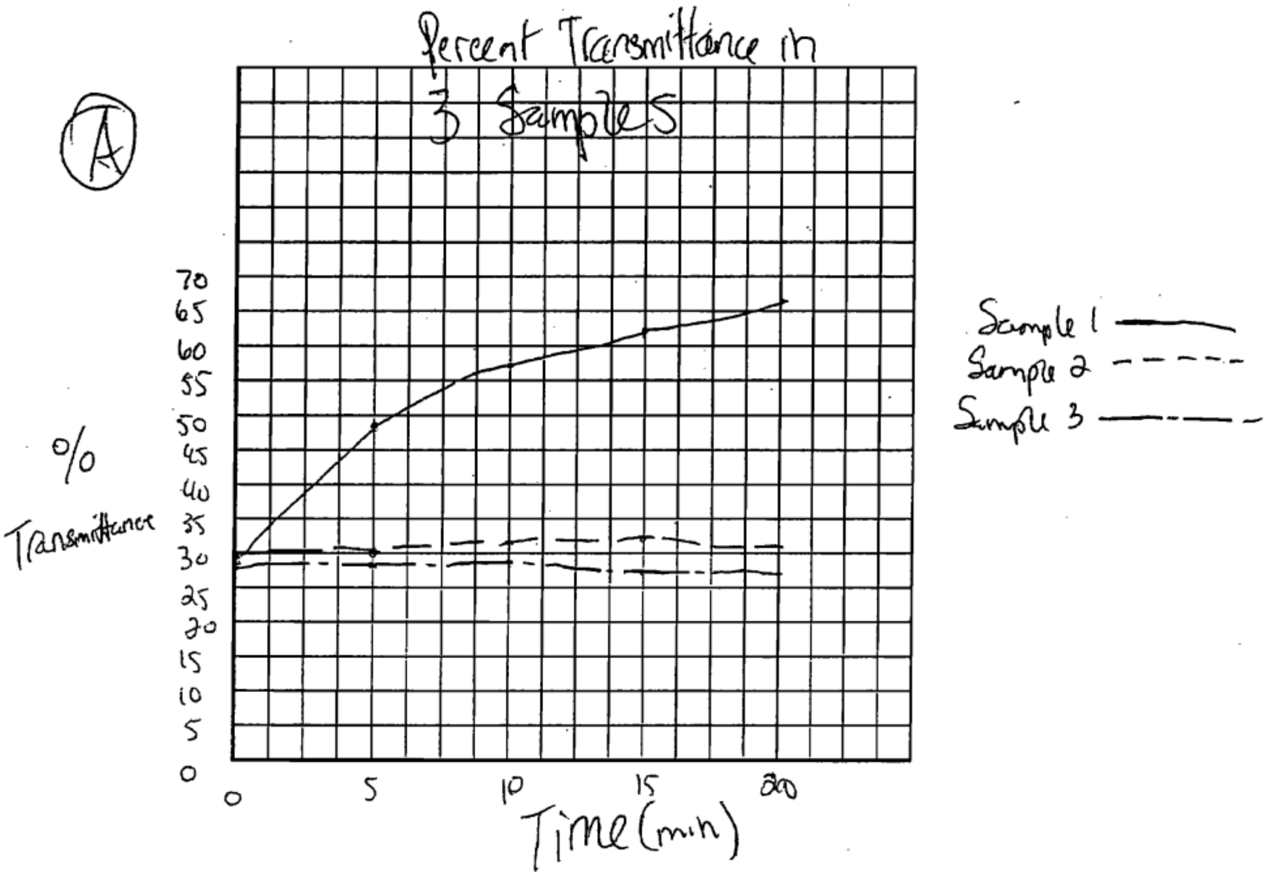
1 point correct explanation for 1% line — must include a discussion of rate; connects concentration of NaCl with diffusion rate

1 point correct explanation for 10% line — must include a discussion of rate; connects concentration of NaCl with diffusion rate

or

1 point general explanation that solute concentration affects the rate of diffusion; answers that attempt to explain the 0%, 1% or 10 % NaCl lines are not eligible to receive this point

2004 #3a

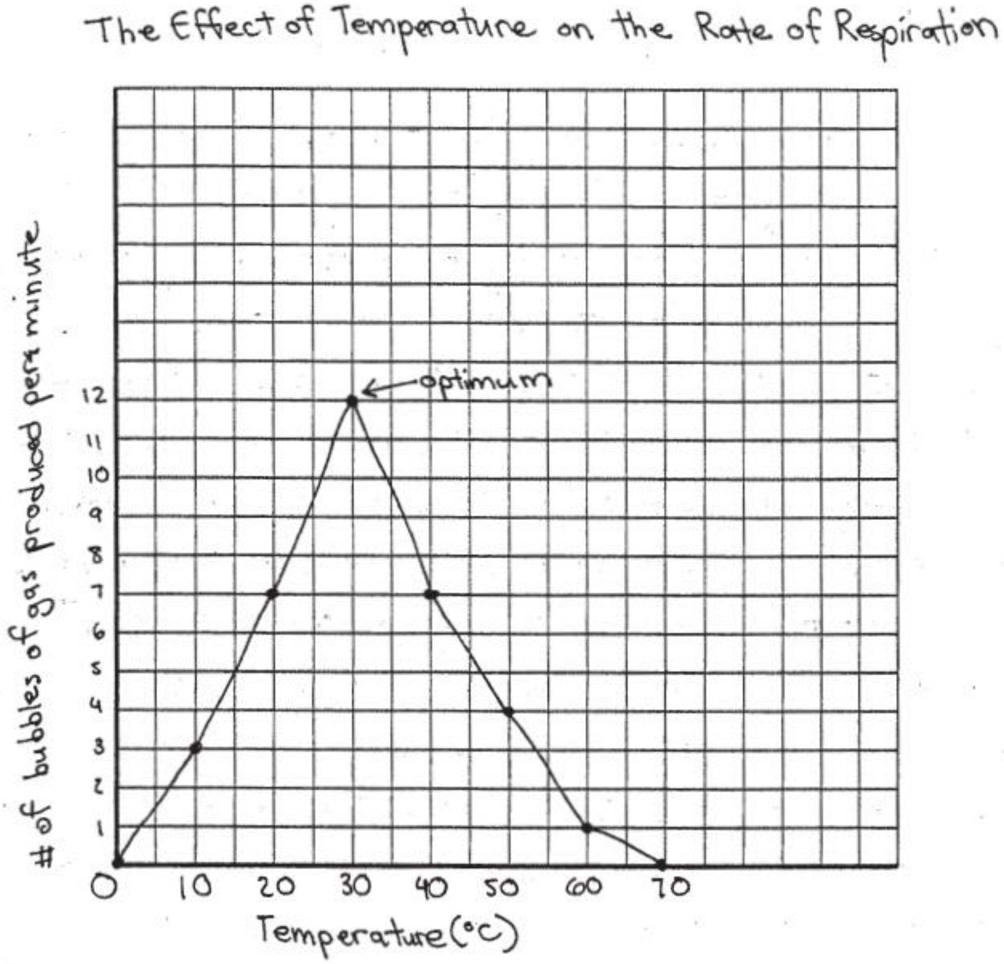


(a) On the axes provided, **construct** and **label** a graph showing the results for the three samples.
(1point each; 3-point maximum)

- ♦ Orientation of axes is correct: x-axis is time/minutes, y-axis is light transmittance/%
- ♦ Data are plotted correctly (one misplaced data point is permissible)
- ♦ Graph is accurate: must include proper scaling and correct labels and units of measurement and key

2005 #1a

(a)



Part A: Graph and Optimum Temperature (3 points maximum)

Graph Setup (1 point)

Must contain:

- Title/Legend and Y-axis [Bubbles of gas/Min]
- X-axis [Temperature (°C)]
- Correct measurement units and scaling for axes

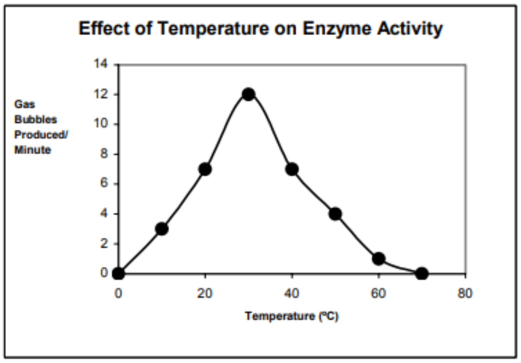
Data Plotted (1 point)

- Correctly plotted points in proper orientation
- Points may or may not be connected with a line
- Bar graph acceptable

Optimum Temperature (1 point)

- 30° C, or between 20° C and 40° C either clearly indicated on the graph or in a sentence

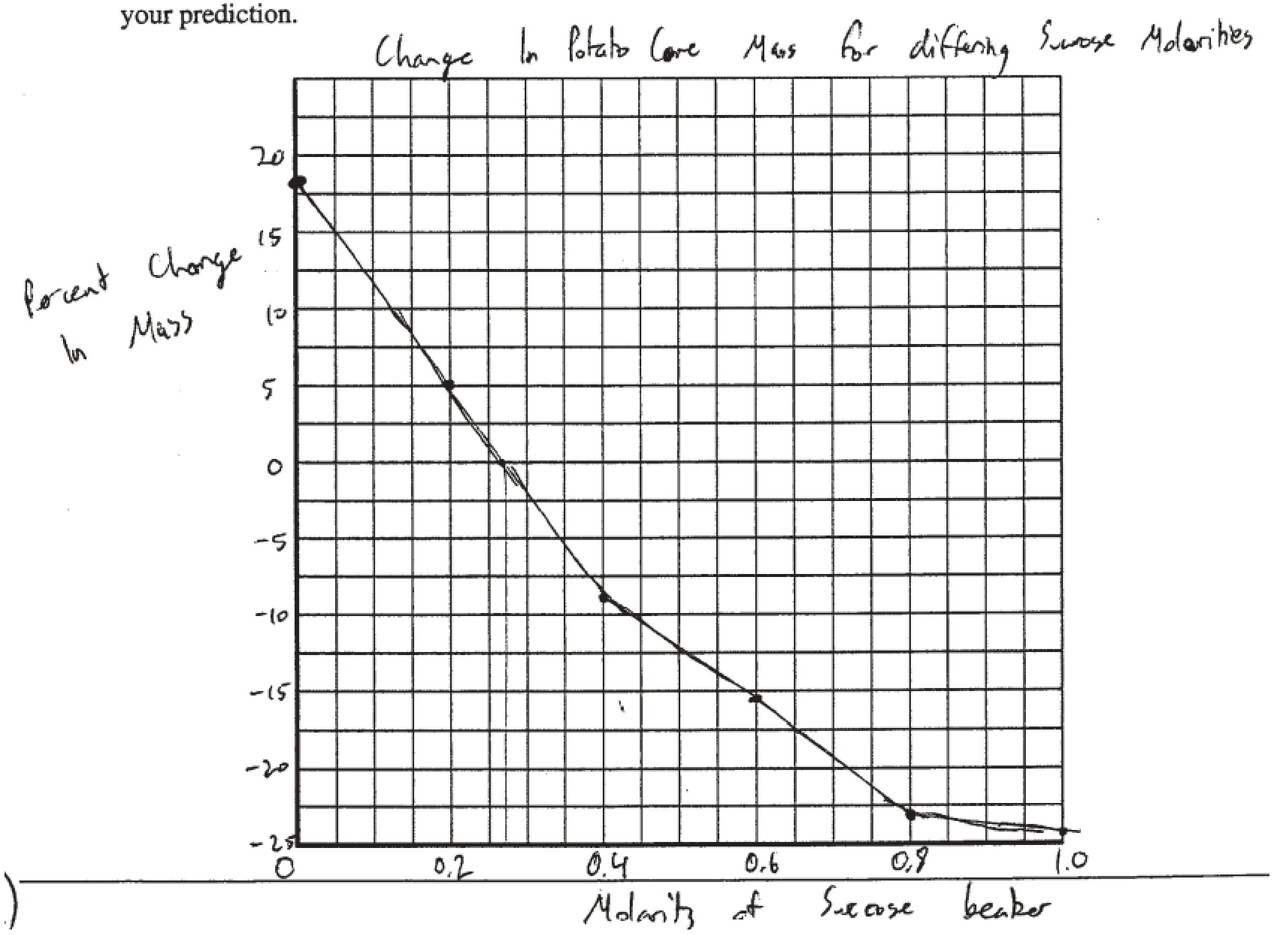
Part B: Analyze and Explain the Results (4 points maximum)



2005(B) #4a

(a)

your prediction.

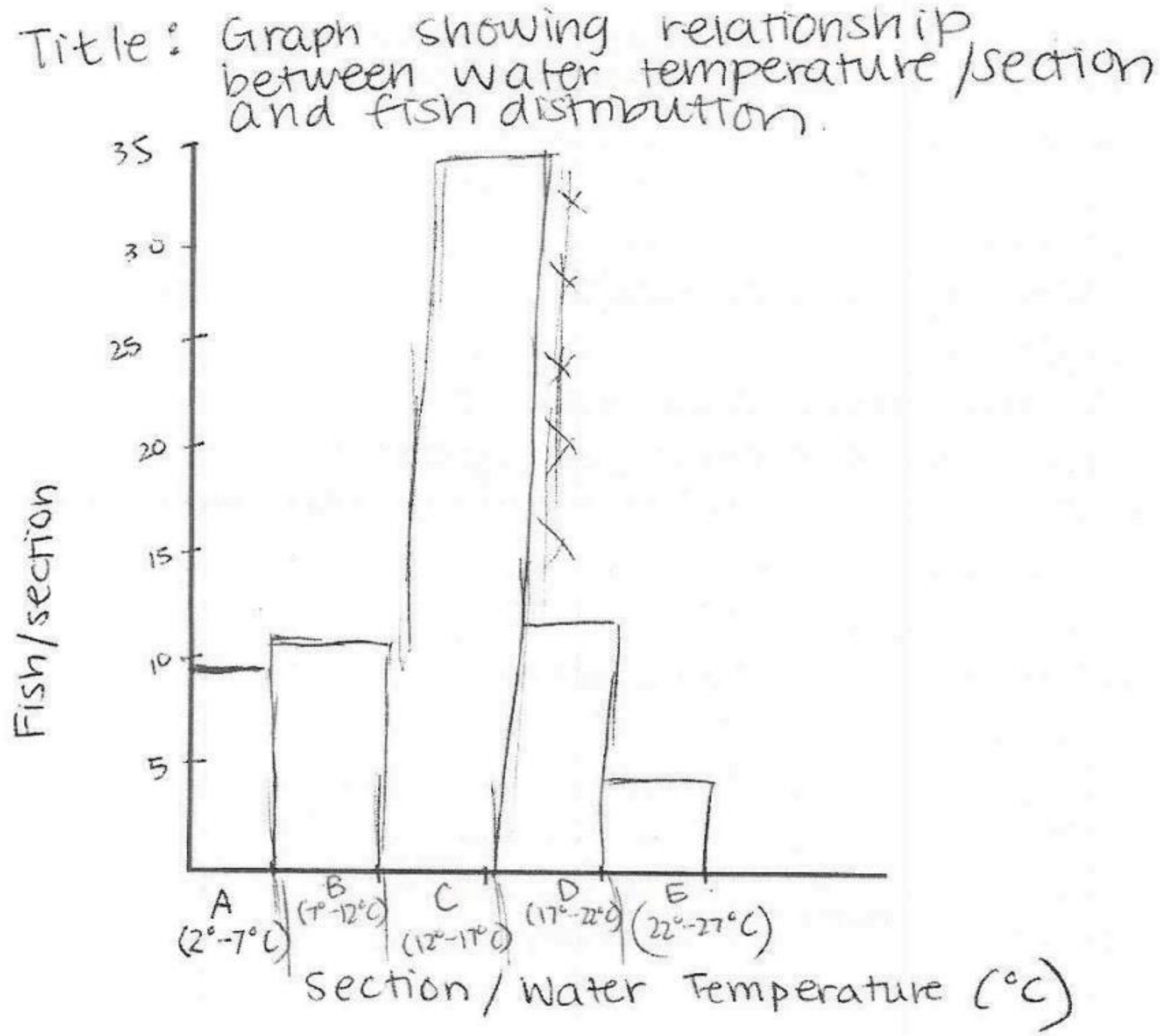


Part (a) (3 points maximum)

- Orientation of axes, labels, scales, units.
- Data points (one mistake permitted) and line drawn.
- Determine molar concentration of potato cells. (Note: This point must be read from graph. It should fall into the range of 0.25 to 0.4 *M*.)

2009 #1a

(a)

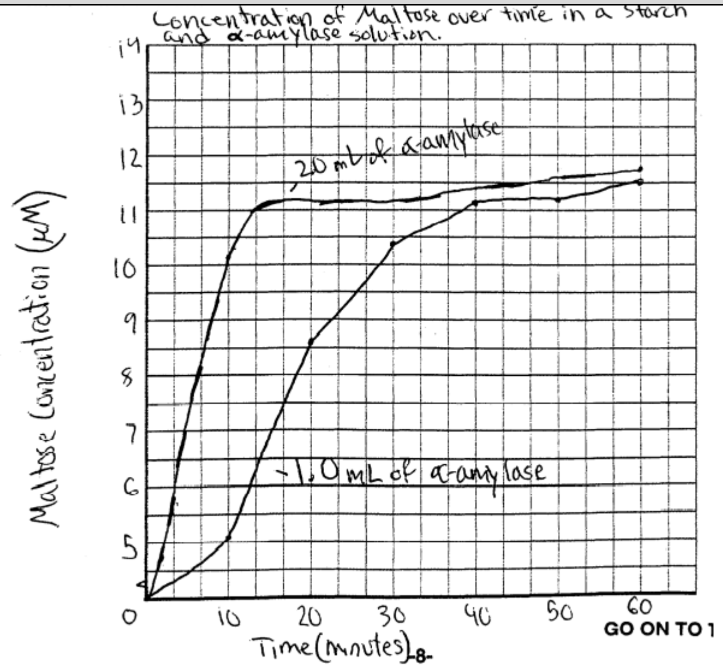


(a) On the axes provided, **construct** the appropriate type of labeled graph showing the relationship between water temperature and fish distribution. **Summarize** the outcome of the experiment. **(4 points maximum)**

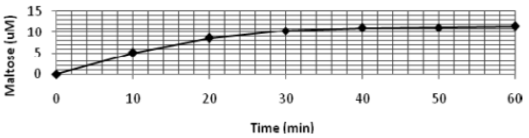
Graph **(1 point each; 3 points maximum for graph)**	**Summarize** **(1 point maximum for summary)**
• Correctly labeled and scaled axis o Temperature range may be indicated by section with legend • Correct orientation: x-axis = temp; y-axis = # fish observed • Correct bar graph/scatter plot o Discrete data points only if range is indicated o NO point for line graph	• Fish were distributed by temperature, e.g., most fish were observed at moderate temperature range, or 12–17°C

2010 #2a

(a)



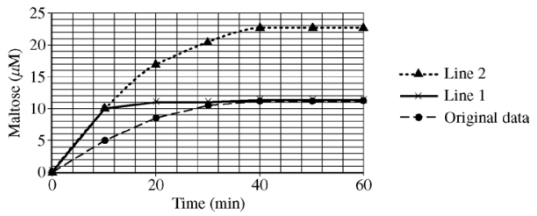
Graph the data on the axes provided and **calculate** the rate of the reaction for the time period 0 to 30 minutes. **(4 points maximum)**



Graph 1 point each (3 points maximum)	Calculation (1 point maximum)
• Correct orientation of the independent (time) and dependent (maltose) variables. • Correct display of units and intervals **(scale and labels)**. • Correct graphing of **all** data points on a properly scaled and oriented graph **(0–60 minutes)**.	• Correct setup **or** rate calculation (0.3–0.4 μM/min or, e.g., 1μM/3 min, 10.4 μM/30 min or 10.4–0.0 /30–0 μM/min), **with units**. (No points if setup is incorrect or if calculated number is wrong and contradicts a correct setup.)

(c)

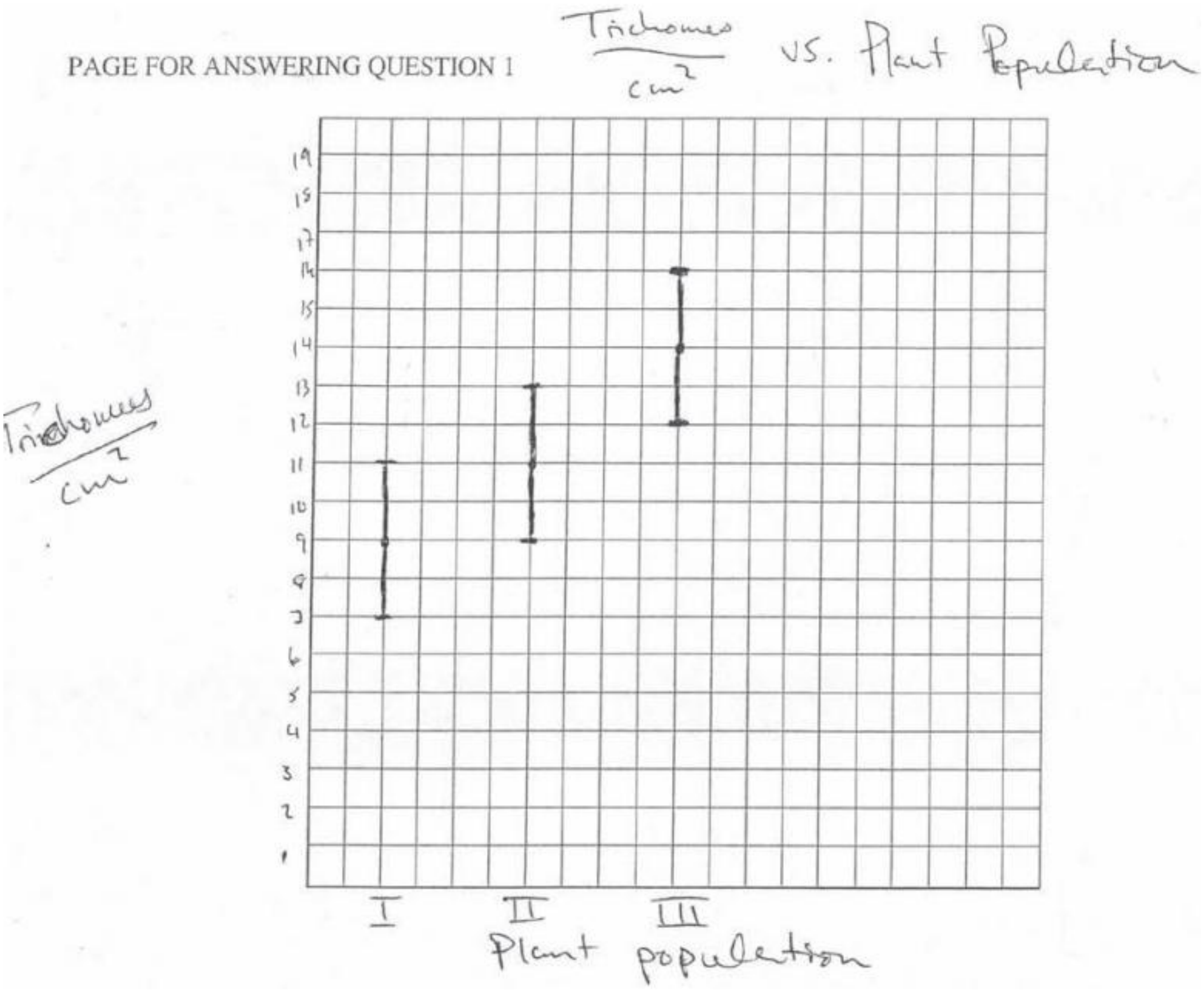
Draw and **label** another line on the graph to predict the results if the concentration of α-amylase was doubled. **Explain** your predicted results. **(2 points maximum)**



Drawing and labeling point (1 point maximum)	Explanation point (1 point maximum)
• Drawing and labeling of new line showing appropriate prediction (increased initial rate). ○ **Draw either line 1 OR line 2.**	• Line 1: Substrate is consumed more quickly because twice as much enzyme is present, but overall final product concentration remains the same. • Line 2: More product is formed at each time point because twice as much enzyme is present; product formation levels off as enzyme loses activity.

2014 #1a

(a)



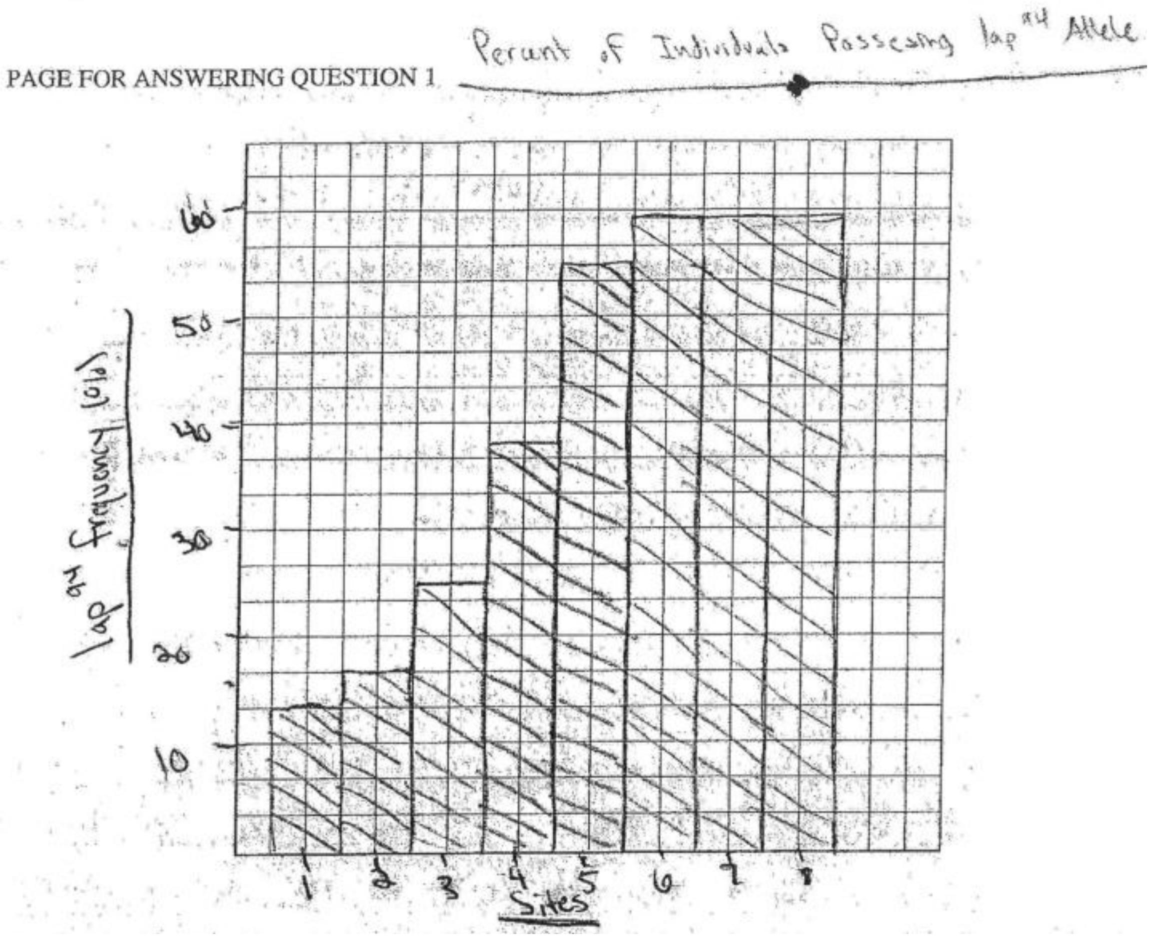
(a) On the axes provided, **create** an appropriately labeled graph to illustrate the sample means of the three populations to within 95 percent confidence (i.e., sample mean ± 2 SEM). (**3 points maximum**; LO 1.1)

- Correctly labeled, scaled, with proper units
- Bar graph or modified bar graph with appropriately plotted means
- 2x standard error (SEM) above and below means

2016 #1a

(a)

PAGE FOR ANSWERING QUESTION 1



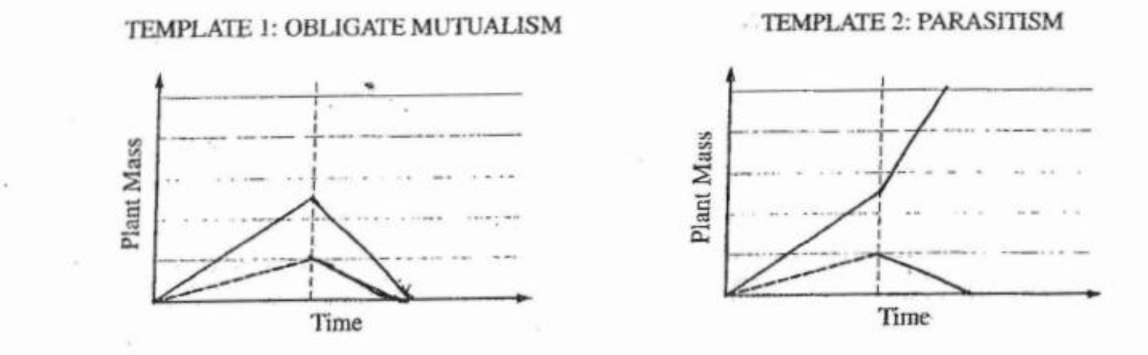
(a) On the axes provided, **construct** an appropriately labeled bar graph to illustrate the observed frequencies of the *lap*^{94} allele in the study populations. **(3 points)**

Construct graph (3 points)

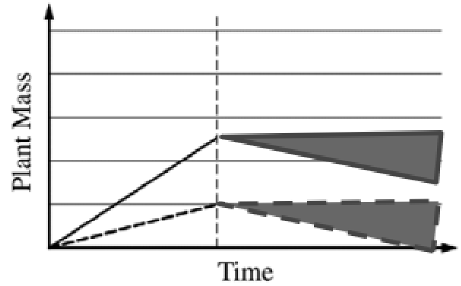
- Correctly plotted bar graph that accurately represents the trend
- Correct axis labeling
- Correct scale and units

2016 #5

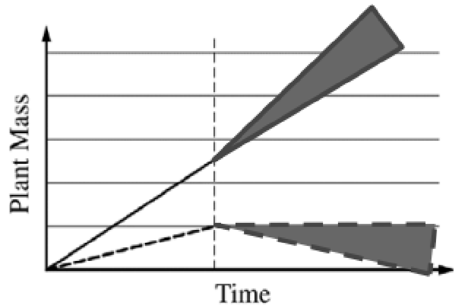
(a)



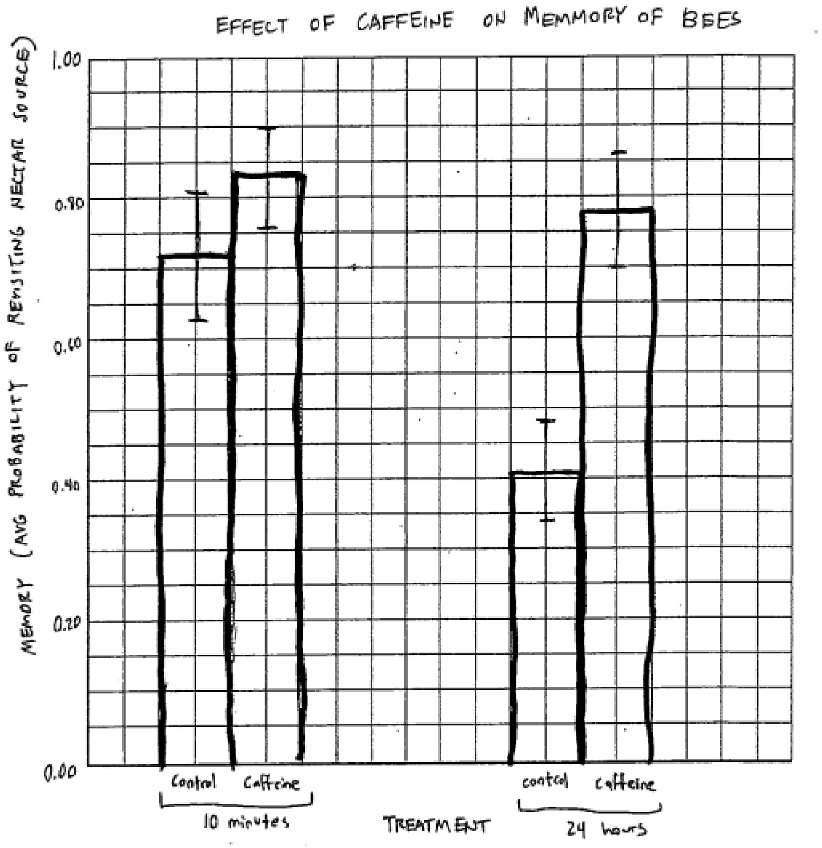
TEMPLATE 1: OBLIGATE MUTUALISM

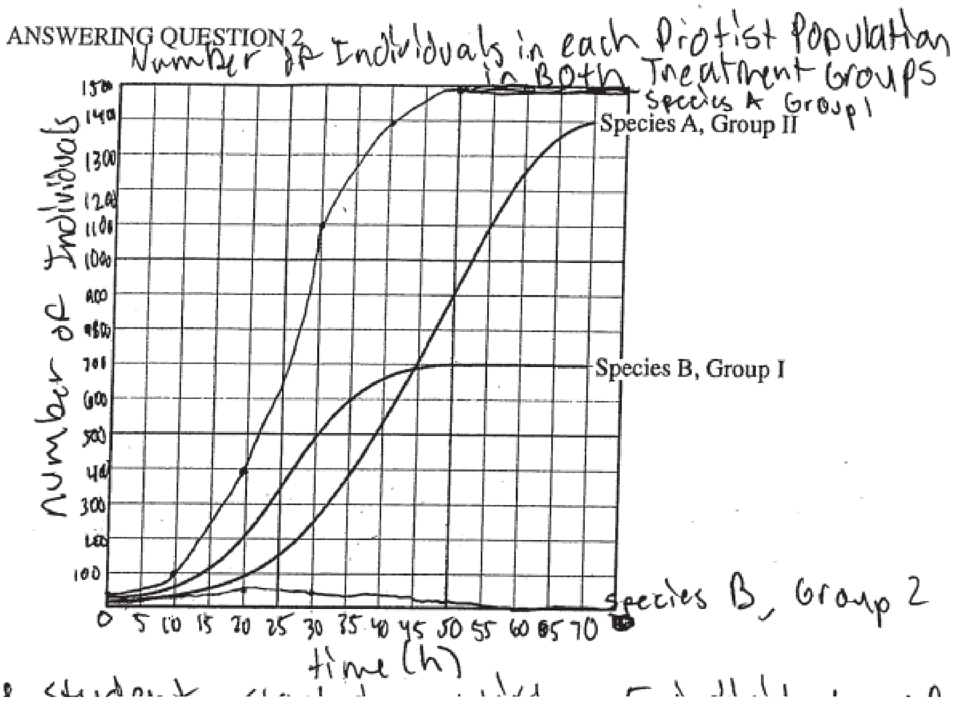


TEMPLATE 2: PARASITISM



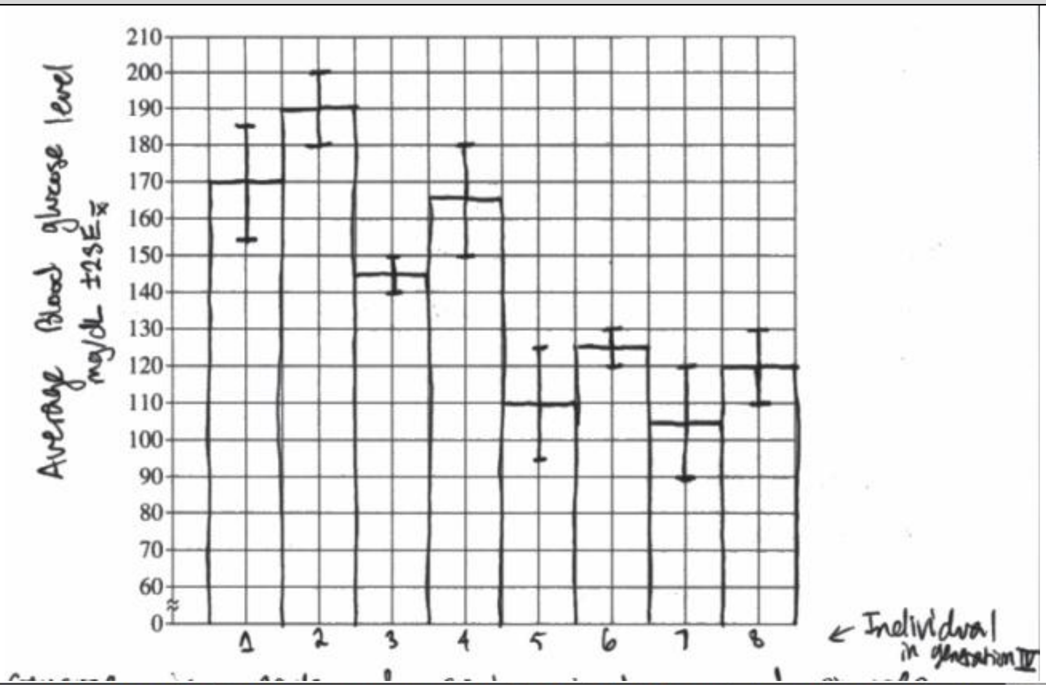
	Graph characteristics (1 point each graph; 2 points maximum)	**Justification (1 point each box; 2 points maximum)**
Obligate Mutualism	Both of the growth curves level off or decline.	• Each species depends on the other for survival. • Without the relationship, both species are harmed.
Parasitism	Species 1 continues to increase while species 2 levels off or declines.	• The parasite requires an association with the host to survive but harms the host. • Without the relationship, the parasite cannot survive while the host continues to grow.

2017 #1a	
(a)	 **Construct graph (3 points)** • Correctly plotted means on a bar graph/modified bar graph • Appropriate labels, units, and scaling • Correctly plotted error bars

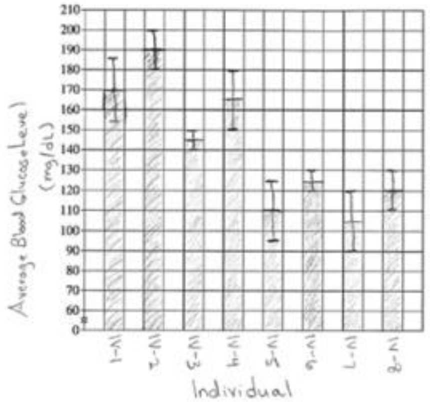
2019 #2a	
(a)	 **Completion (3 points)** • Correctly plotted lines for remaining two treatments • Correctly labeled axes including units • Correctly labeled data lines

2021 #2b

(b)



Use the template provided to **construct** an appropriately labeled graph based on the data in Table 1. **3 points**



- Point distribution: Axis labels; plotting in a bar graph or modified bar graph; error bars

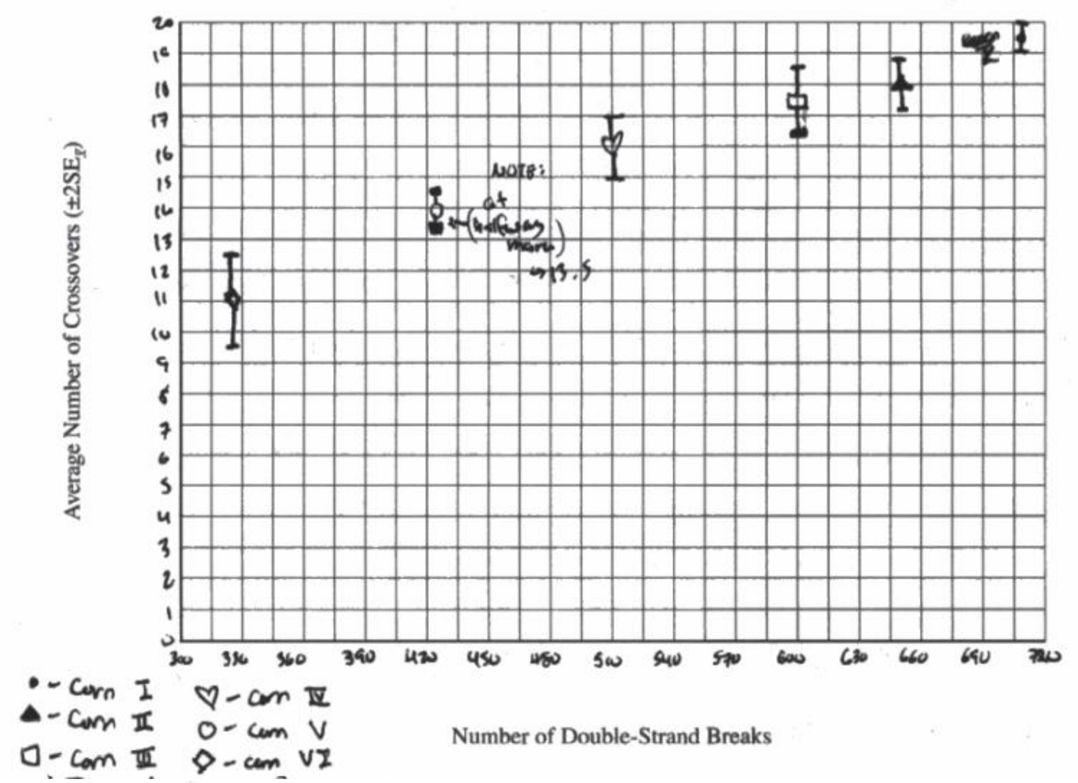
Determine one individual who is both at risk of developing the disorder and has a significantly different blood glucose level from that of individual IV-1. **1 point**

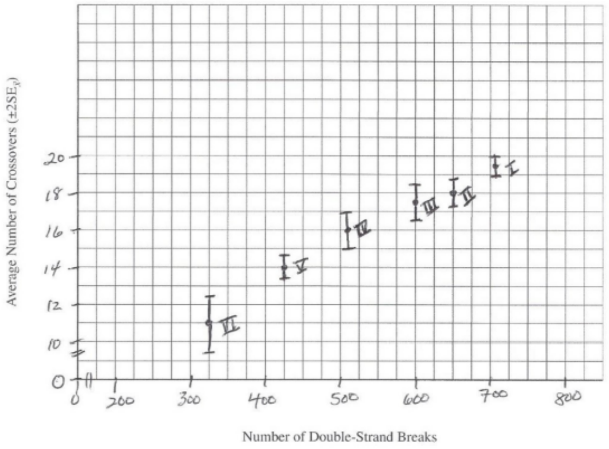
- IV-3

Total for part (b) 4 points

2022 #2b

(b)



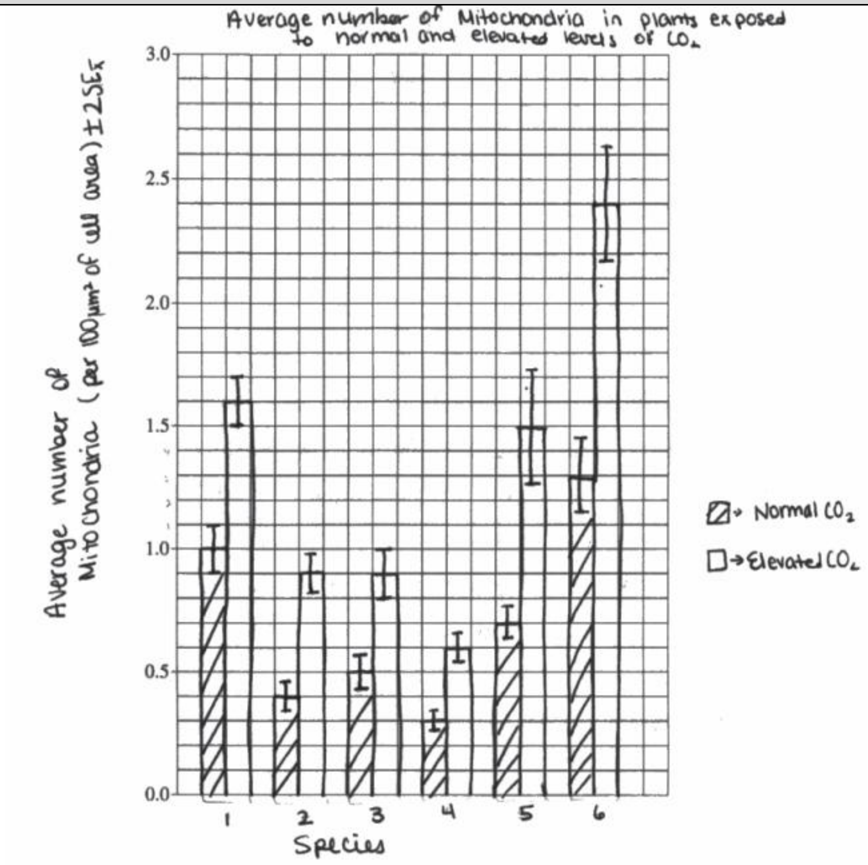


- Appropriate axis scaling

Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. • Accurately plotted X,Y graph with separate points for the average number of crossovers for each strain	**1 point**
Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1 and allows examination of a possible correlation between double-strand breaks and crossovers. • Accurate error bars	**1 point**
Based on the data, **determine** whether corn strains I, II, and III differ in their average number of crossovers. • There is no (statistical) difference (in the average number of crossovers) between strains II and III. Strain I is higher/different (in the average number of crossovers) compared with strains II and III.	**1 point**
Total for part (b)	**4 points**

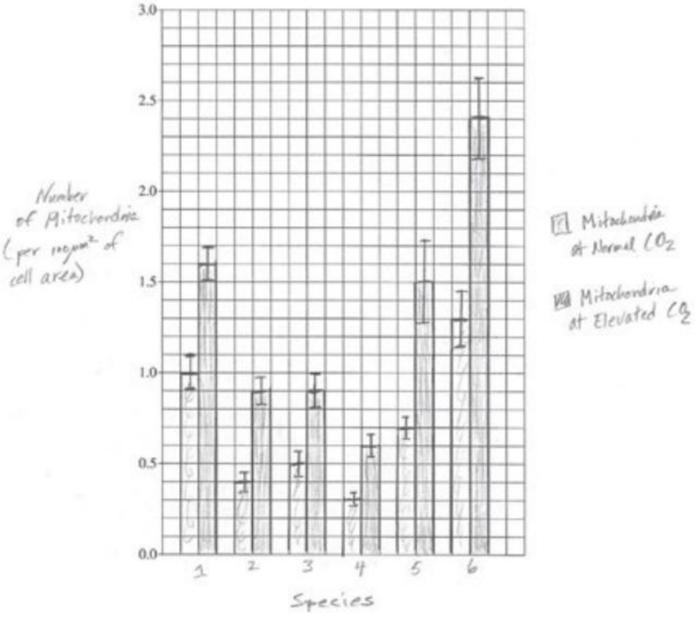
2023 #2b

(b)



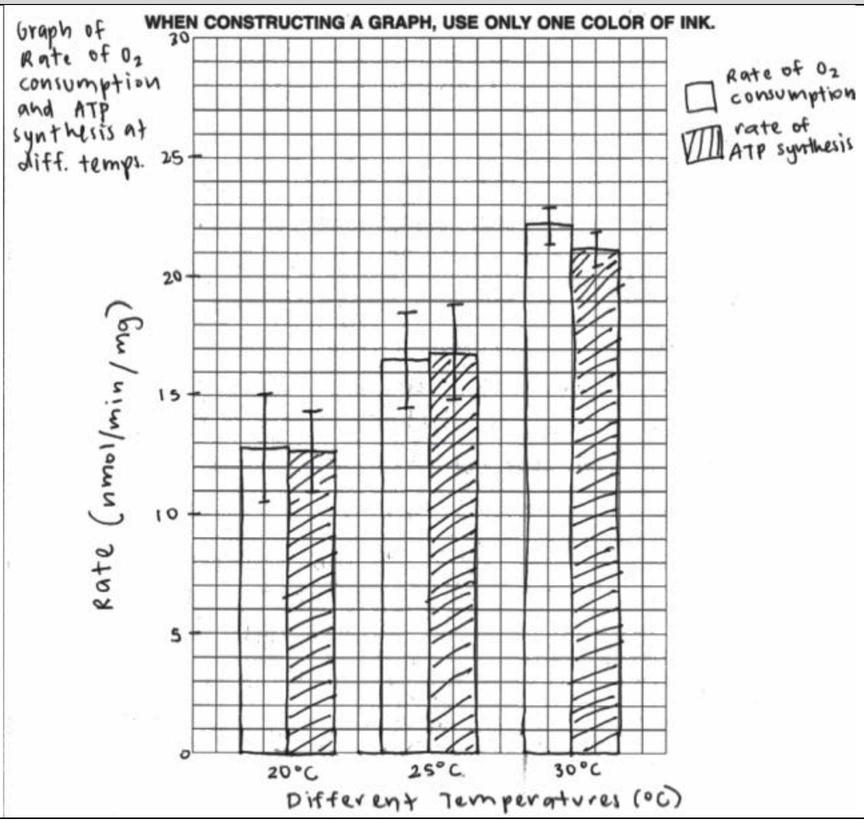
Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1.

Sample response:



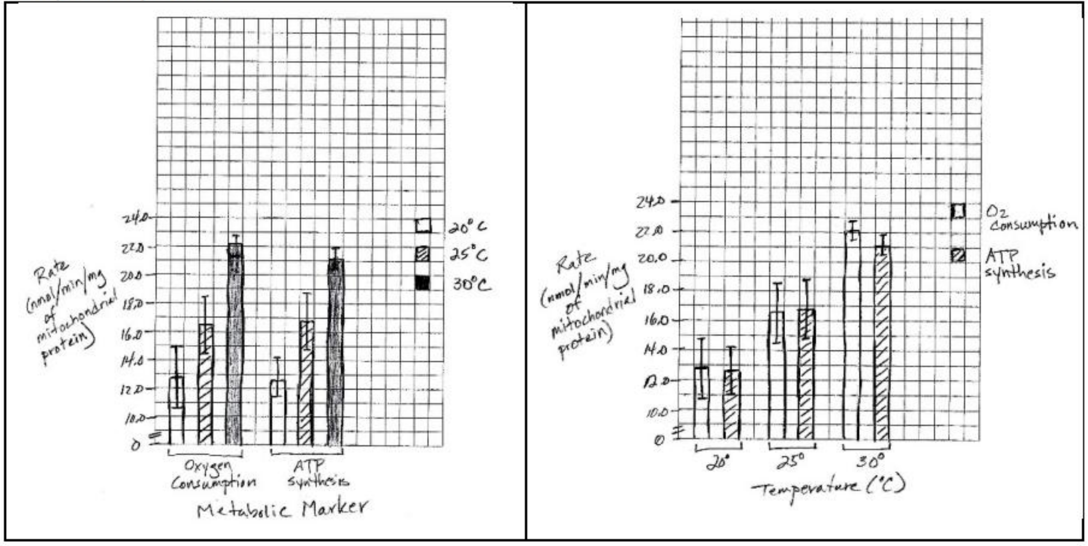
- Appropriate labelling

	Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. • Data are represented in a bar/modified bar graph. Using the template in the space provided for your response, **construct** an appropriately labeled graph that represents the data in Table 1. • Data points and error bars are correctly plotted. **Determine** which species show(s) a difference in the number of mitochondria between normal and elevated levels of CO_2. • All of the species
(c)	Based on the data in Table 1, **describe** the relationship between the level of CO_2 and the average number of mitochondria per unit area of a cell. Accept one of the following: • The number of mitochondria is greater under conditions of elevated CO_2 (than under normal CO_2). • It is a positive relationship/correlation.

<table>
<tr><th colspan="2">2024 #2b</th></tr>
<tr><td>(b)</td><td>


</td></tr>
</table>

Sample Responses:



- Data are represented in a bar graph.
- Graph is appropriately labeled.
- Data points and error bars are correctly plotted.
- 30

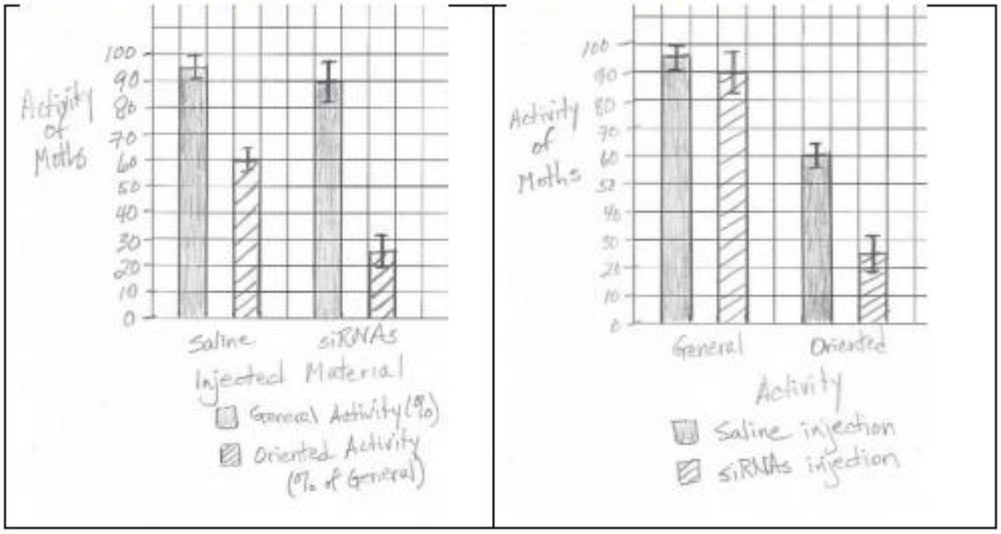
(c) Accept one of the following:

- As the temperature increases, the rate of ATP synthesis also increases.
- There is a positive relationship (between temperature and ATP synthesis).
- Temperature and ATP synthesis are directly correlated.

2025 #2

(b) i.

- Data are represented in a bar/modified bar graph.
- Examples of acceptable responses may include the following:

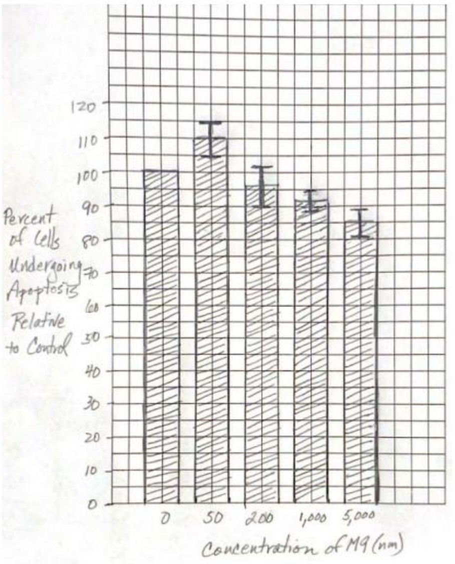


- Data and error bars are accurately plotted.
- Graph is appropriately labeled.

II.

- Oriented activity (was affected).

(c)	i. Examples of acceptable responses may include the following: • The control/saline-treated group • Male moths injected with saline/control solution

2026 CED Q2	
(b)	i. Sample response:  ▪ Data are represented in a bar graph. ▪ Data and error bars are accurately plotted. ▪ Graph includes labeled axes and legend. II. ▪ 200 nM and 1,000 nM

Calculation FRQ Practice

To provide you specific practice with calculations, I have compiled just the calculate components from the 1999 – 2019, 2021 - 2024 FRQs. The questions from 2013 – 2019, 2021 – 2024 might be repeats as they could have been used in the unit specific FRQ sections.

2003 #1b

In fruit flies, the phenotype for eye color is determined by a certain locus, ***E*** indicates the dominant allele and ***e*** indicates the recessive allele. The cross between a male wild-type fruit fly and a female white-eyed fruit fly produced the following offspring.

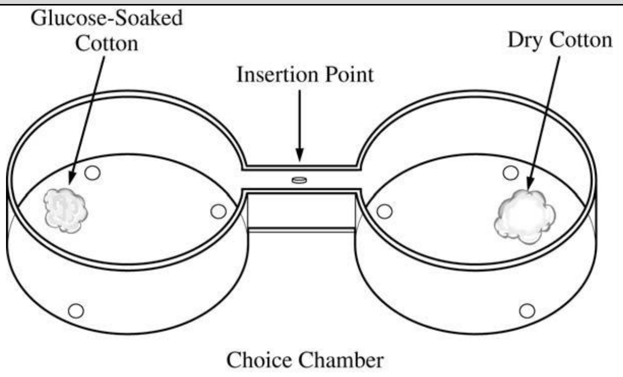
	Wild-type Male	Wild-type Female	White-eyed Male	White-eyed Female	Brown-eyed Female
F1	0	45	55	0	1

The wild-type and white-eyed individuals from the F1 generation were then crossed to produce the following offspring.

F2	23	31	22	24	0

(b) Use a Chi-squared test on the F2 generation data to analyze your prediction of the parental genotypes of X^eX^e and X^EY. Show all your work and explain the importance of your final answer.

2013 #1c



In an investigation of fruit-fly behavior, a covered choice chamber is used to test whether the spatial distribution of flies is affected by the presence of a substance placed at one end of the chamber. To test the flies' preference for glucose, 60 flies are introduced into the middle of the choice chamber at the insertion point indicated by the arrow in the figure above. A cotton ball soaked with a 10% glucose solution is placed at one end of the chamber, and a dry cotton ball with no solution is placed at the other end. The positions of flies are observed and recorded every minute for 10 minutes.

The experiment described above is repeated with ripe bananas at one end and unripe bananas at the other end. Once again the positions of the flies are observed and recorded every minute for 10 minutes. The positions of flies after 1 minute and after 10 minutes are shown in the table below.

DISTRIBUTION OF FLIES IN CHOICE CHAMBER

Time (minutes)	Position in Chamber		
	End with Ripe Banana	Middle	End with Unripe Banana
1	21	18	21
10	45	3	12

(c) **Perform** a chi-square test on the data for the 10-minute time point in the banana experiment. Specify the null hypothesis that you are testing and **enter** the values from your calculations in the table below.

PART (C): CHI-SQUARE CALCULATION

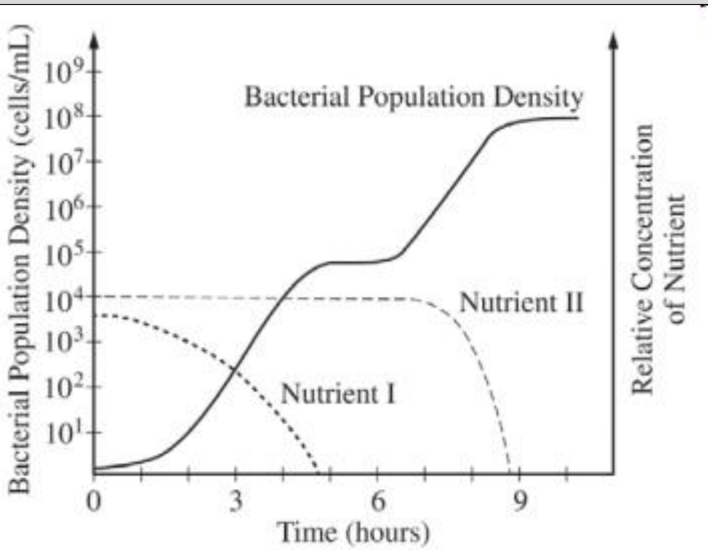
Null Hypothesis:

	Observed (o)	Expected (e)	$(o - e)^2/e$
End with ripe banana			
Middle			
End with unripe banana			
Total			

2015 #2c

(c) Cellular respiration includes the metabolic pathways of glycolysis, the Krebs cycle, and the electron transport chain, as represented in the figures. In cellular respiration, carbohydrates and other metabolites are oxidized, and the resulting energy-transfer reactions support the synthesis of ATP.

A researcher estimates that, in a certain organism, the complete metabolism of glucose produces 30 molecules of ATP for each molecule of glucose. The energy released from the total oxidation of glucose under standard conditions is 686 kcal/mol. The energy released from the hydrolysis of ATP to ADP and inorganic phosphate under standard conditions is 7.3 kcal/mol. **Calculate** the amount of energy available from the hydrolysis of 30 moles of ATP. **Calculate** the efficiency of total ATP production from 1 mole of glucose in the organism. **Describe** what happens to the excess energy that is released from the metabolism of glucose.

	2016 #2b
	 **Figure 1. Bacterial population growth in the presence of two nutrients (nutrient I and nutrient II)** Bacteria can be cultured in media with a carefully controlled nutrient composition. The graph above shows the growth of a bacterial population in a medium with limiting amounts of two nutrients, I and II.
(b)	Using the data, **calculate** the growth rate in $\frac{cells}{mL\ x\ hour}$ of the bacterial population between hours 2 and 4.

	2019 #3c
	The pyruvate dehydrogenase complex (PDC) catalyzes the conversion of pyruvate to acetyl-CoA, a substrate for the Krebs (citric acid) cycle. The rate of pyruvate conversion is greatly reduced in individuals with PDC deficiency, a rare disorder.
(c)	PDC deficiency is caused by mutations in the *PDHA1* gene, which is located on the X chromosome. A male with PDC deficiency and a homozygous female with no family history of PDC deficiency have a male offspring. **Calculate** the probability that the male offspring will have PDC deficiency.

2021 #1c

Polycystic kidney disease (PKD) is an inherited disease that causes water loss from the body and affects cell division in the kidneys. Because water movement across cell membranes is related to ion movement, scientists investigated the role of Na^+/K^+ ATPase (also known as the sodium/potassium pump) in this disease. Ouabain, a steroid hormone, binds to the Na^+/K^+ ATPase in plasma membranes. Individuals with PKD have a genetic mutation that results in an increased binding of ouabain to the Na^+/K^+ ATPase. The scientists treated normal human kidney (NHK) cells and PKD cells with increasing concentrations of ouabain and measured the number of cells (Figure 1) and the activity of the Na^+/K^+ ATPase (Figure 2) after a period of time. The scientists hypothesized that a signal transduction pathway that includes the protein kinases MEK and ERK (Figure 3) may play a role in PKD symptoms.

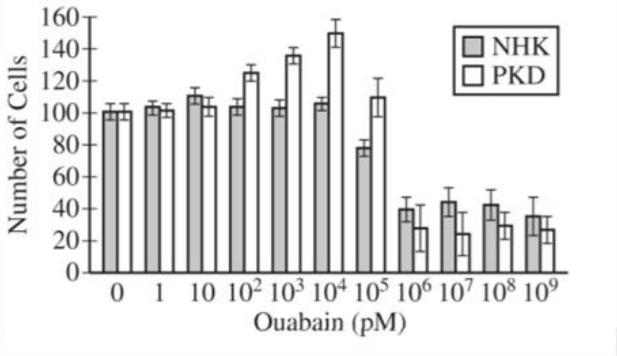


Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

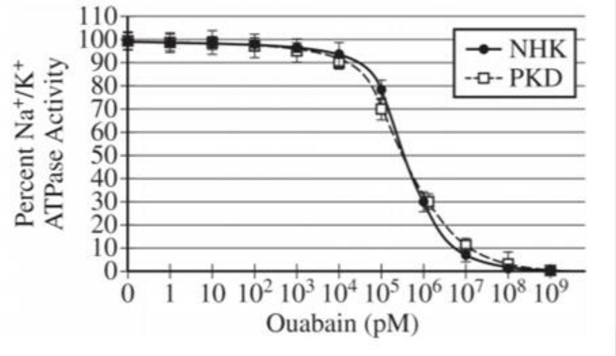


Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.

(c) The scientists determined that Na^+/K^+ ATPase activity in PKD cells treated with 1 pM ouabain is 150 units of ATP hydrolyzed/sec. **Calculate** the expected Na^+/K^+ ATPase activity (units/sec) in PKD cells treated with 10^6 pM ouabain.

2022 #1c

The binding of an extracellular ligand to a G protein-coupled receptor in the plasma membrane of a cell triggers intracellular signaling (Figure 1, A). After ligand binding, GTP replaces the GDP that is bound to Gs**α**, a subunit of the G protein (Figure 1, B). This causes Gs**α** to activate other cellular proteins, including adenylyl cyclase that converts ATP to cyclic AMP (cAMP). The cAMP activates protein kinases (Figure 1, C). In cells that line the small intestine, a cAMP -activated protein kinase causes further signaling that ultimately results in the secretion of chloride ions (Cl–) from the cells. Under normal conditions, Gs**α** hydrolyzes GTP to GDP, thus inactivating adenylyl cyclase and stopping the signal (Figure 1, A).

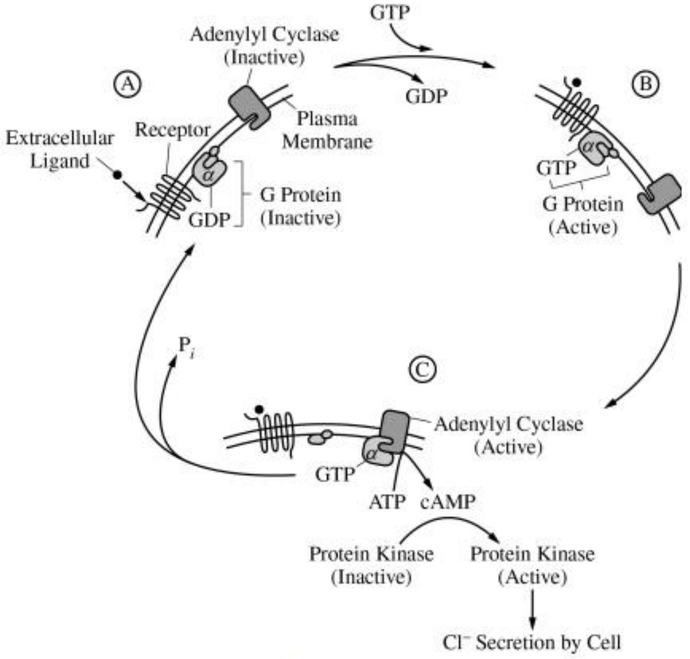

GTP
Adenylyl Cyclase (Inactive)
GDP
A
B
Extracellular Ligand
Receptor
Plasma Membrane
G Protein (Inactive)
GDP
GTP
G Protein (Active)
P_i
C
Adenylyl Cyclase (Active)
GTP
ATP
cAMP
Protein Kinase (Inactive)
Protein Kinase (Active)
Cl⁻ Secretion by Cell

Figure 1. Under normal conditions, ligand binding to a G protein-coupled receptor results in chloride ion transport from an intestinal cell.

Individuals infected with the bacterium Vibrio cholerae experience severe loss of water from the body (dehydration). This is due to the effects of the bacterial cholera toxin that enters intestinal cells. Scientists studied the effects of cholera toxin on four samples of isolated intestinal cell membranes containing the G protein-related signal transduction components shown in Figure 1. GTP was added to samples II and IV only; cholera toxin was added to samples III and IV only. The scientists then measured the amount of cAMP produced by the adenylyl cyclase in each sample (Table 1).

TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	−	−	0.5
II	+	−	10.0
III	−	+	0.5
IV	+	+	127.0

present, +; absent, −

(c) **Calculate** the percent change in the rate of cAMP production due to the presence of cholera toxin in sample IV compared with sample II.

2023 #1c

In eukaryotic microorganisms, the PHO signaling pathway regulates the expression of certain genes. These genes, *Pho* target genes, encode proteins involved in regulating phosphate homeostasis. When the level of extracellular inorganic phosphate (P_i) is high, a transcriptional activator Pho4 is phosphorylated by a complex of two proteins, Pho80–Pho85. As a result, the *Pho* target genes are not expressed. When the level of extracellular P_i is low, the activity of the Pho80–Pho85 complex is inhibited by another protein, Pho81, enabling Pho4 to induce the expression of these target genes. A simplified model of this pathway is shown in Figure 1.

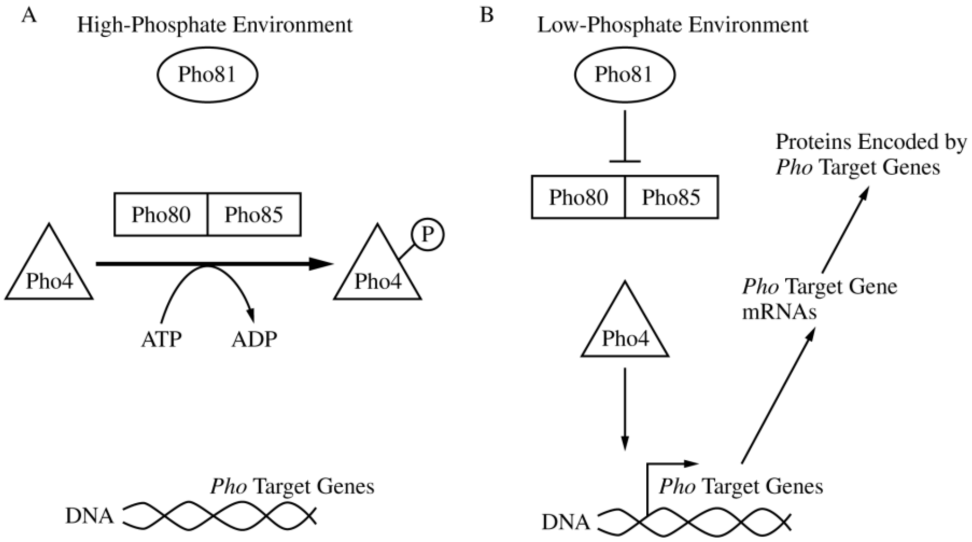

A
High-Phosphate Environment
Pho81
Pho80
Pho85
Pho4
Pho4
P
ATP
ADP
Pho Target Genes
DNA
B
Low-Phosphate Environment
Pho81
Proteins Encoded by *Pho* Target Genes
Pho80
Pho85
Pho Target Gene mRNAs
Pho4
Pho Target Genes
DNA

Figure 1. A simplified model of the regulation of expression of *Pho* target genes in (A) a high-phosphate (high-Pi) environment and (B) a low-phosphate (low-Pi) environment

To study the role of the different proteins in the PHO pathway, researchers used a wild-type strain of yeast to create a strain with a mutant form of Pho81 (*phio81mt*) and a strain with a mutant form of Pho4 (*pho81mt*). In each of these mutant strains, researchers measured the activity of a particular enzyme, APase, which removes phosphates from its substrates and is encoded by PHO1, a Pho target gene (Table 1). They then determined the level of PHO1 mRNA relative to that of the wild-type yeast strain, which was set to 10.

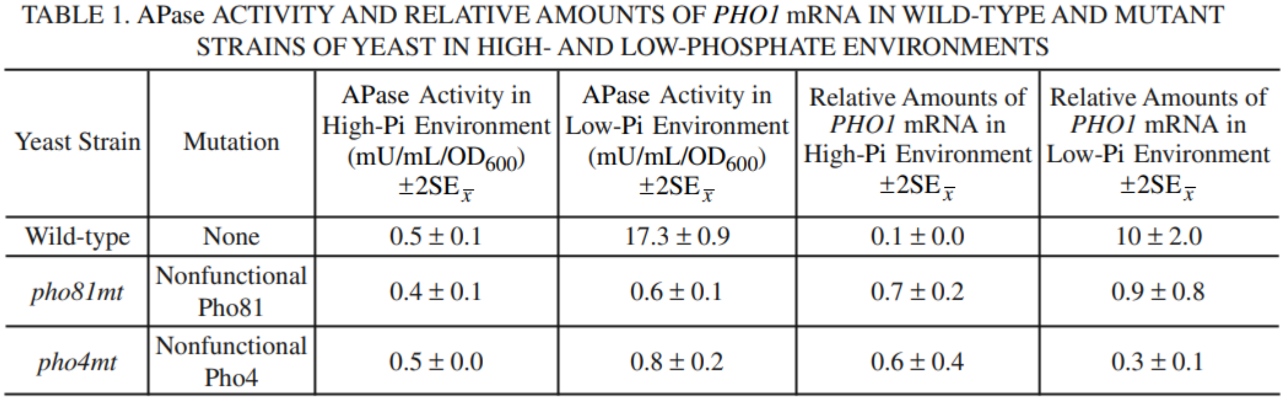


TABLE 1. APase ACTIVITY AND RELATIVE AMOUNTS OF *PHO1* mRNA IN WILD-TYPE AND MUTANT STRAINS OF YEAST IN HIGH- AND LOW-PHOSPHATE ENVIRONMENTS

Yeast Strain	Mutation	APase Activity in High-Pi Environment $(mU/mL/OD_{600})$ $\pm 2SE_{\bar{x}}$	APase Activity in Low-Pi Environment $(mU/mL/OD_{600})$ $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in High-Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in Low-Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 ± 0.1	17.3 ± 0.9	0.1 ± 0.0	10 ± 2.0
pho81mt	Nonfunctional Pho81	0.4 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.9 ± 0.8
pho4mt	Nonfunctional Pho4	0.5 ± 0.0	0.8 ± 0.2	0.6 ± 0.4	0.3 ± 0.1

(c) **Calculate** the percent change in APase activity in wild-type yeast cells in a high-P_i environment compared with that of wild-type cells in a low-P_i environment.

2024 #2

To investigate how increases in environmental temperatures affect the metabolism of certain organisms, researchers incubated liver cells from toads at different temperatures and measured two markers of metabolic activity (Table 1): the rate of oxygen consumption and the rate of ATP synthesis.

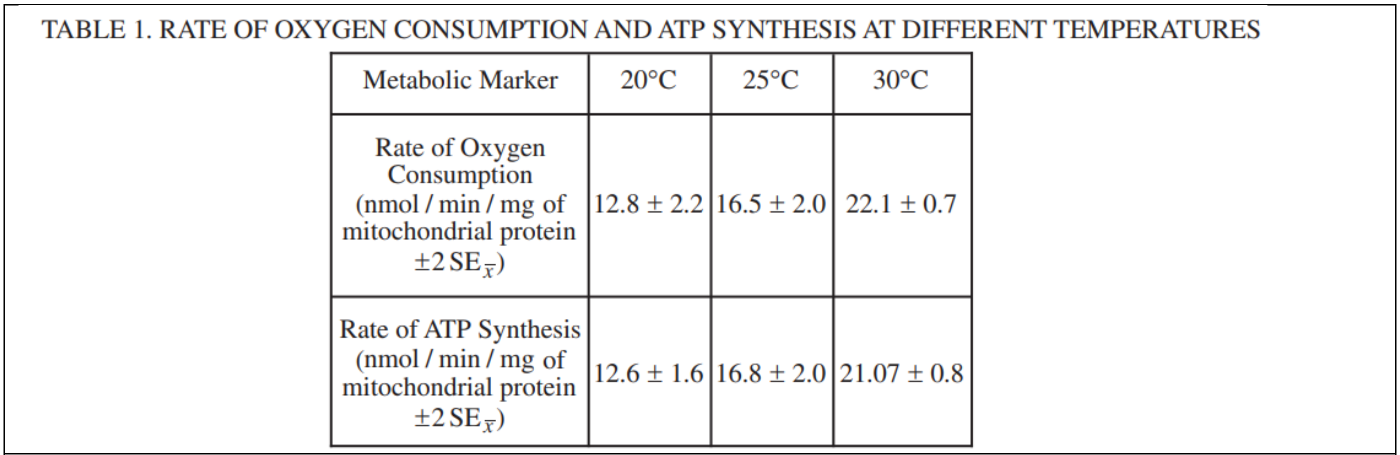


TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

(c)

ii. Based on the data in Table 1, **calculate** the average amount of oxygen consumed, in nmol, for 10 mg of mitochondrial protein after 10 minutes at 25 C° .

2025 #1

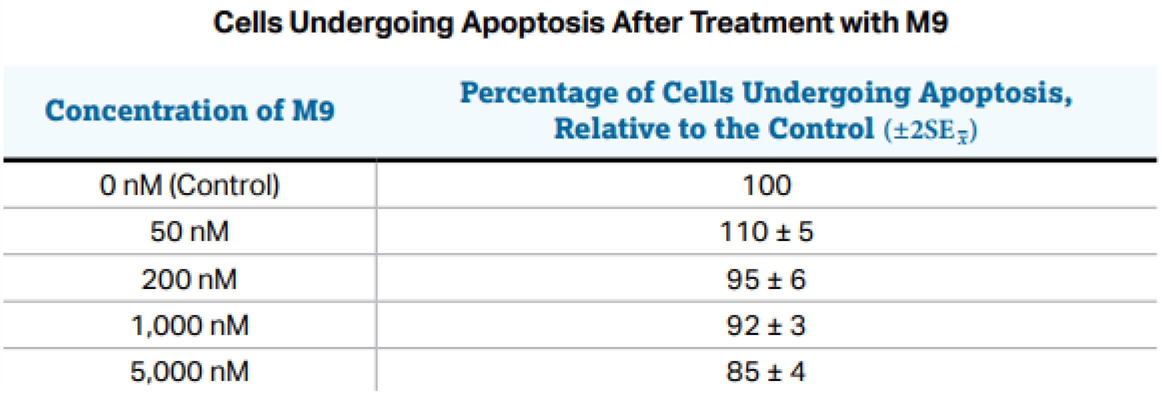
The researchers then measured the amount of each of three different proteins that was transported to the ER in cells treated with Sec62 siRNA or SR siRNA. The researchers calculated the percent transported relative to the cells treated with control siRNA (Figure 2).

(c)

iii. Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, **calculate** the difference in the number of amino acids between the two proteins.

2026 CED Q2

In the second experiment, the researchers investigated the effect of M9 on apoptosis. They incubated cancer cells with solvent alone or with increasing concentrations of M9 and then determined the percentage of cells undergoing apoptosis in each treatment group relative to the control as shown in the table.



Cells Undergoing Apoptosis After Treatment with M9

Concentration of M9	Percentage of Cells Undergoing Apoptosis, Relative to the Control ($\pm 2SE_{\bar{x}}$)
0 nM (Control)	100
50 nM	110 ± 5
200 nM	95 ± 6
1,000 nM	92 ± 3
5,000 nM	85 ± 4

Part C:

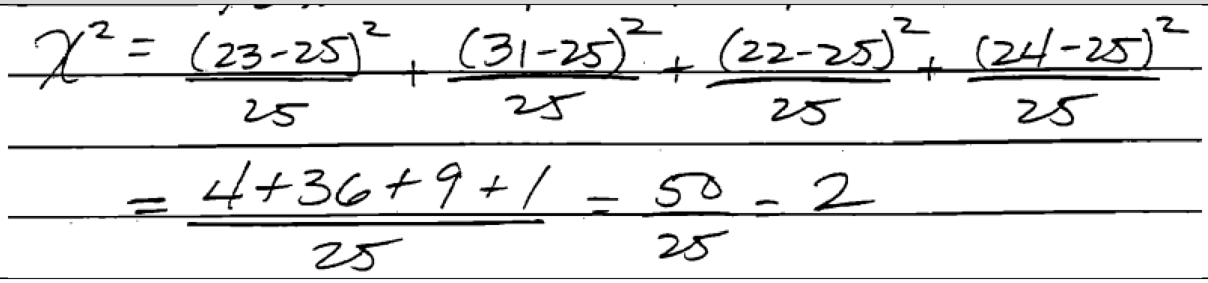
ii. Researchers also investigated the effect of M9 on apoptosis shown in the table. Assuming there were 115,000 cells undergoing apoptosis in the control dish, use the data in the table to **calculate** the average number of cells undergoing apoptosis in the dish treated with 5,000 nM M9.

Calculation FRQ Practice - KEY

The following work on the calculations are from the exemplars found on AP Central for the question.

2003 #1b

(b)

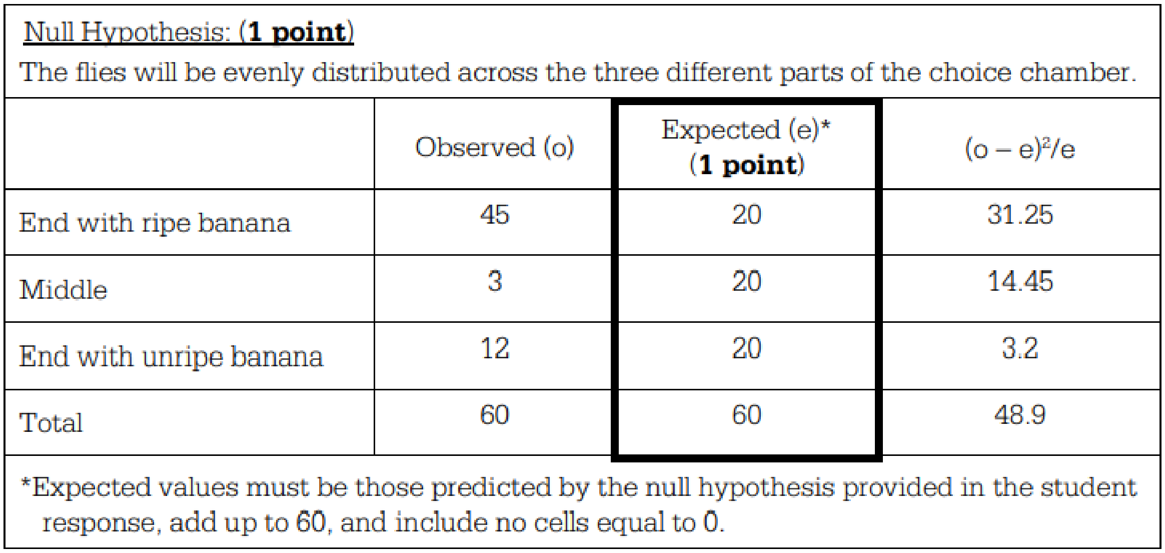


$$\chi^2 = \frac{(23-25)^2}{25} + \frac{(31-25)^2}{25} + \frac{(22-25)^2}{25} + \frac{(24-25)^2}{25}$$

$$= \frac{4+36+9+1}{25} = \frac{50}{25} = 2$$

2013 #1c

(c)



Null Hypothesis: (**1 point**)

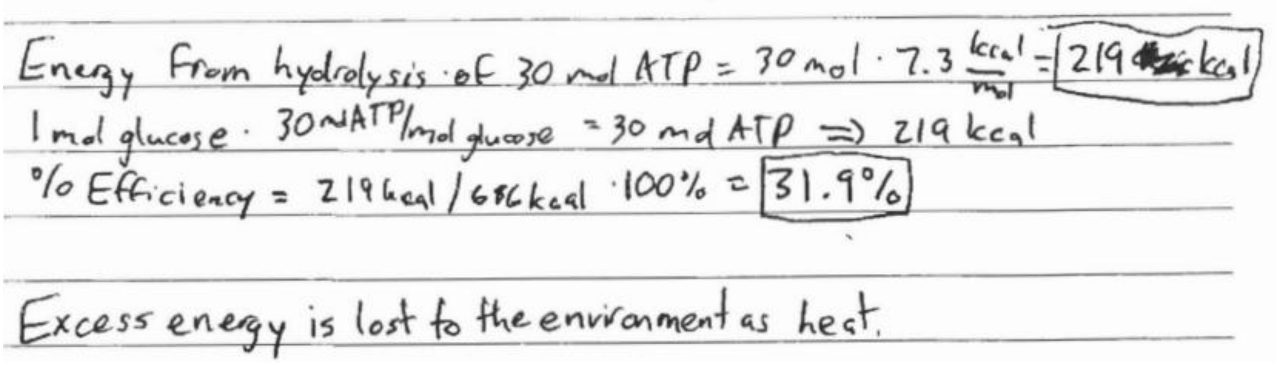
The flies will be evenly distributed across the three different parts of the choice chamber.

	Observed (o)	Expected (e)* (**1 point**)	$(o-e)^2/e$
End with ripe banana	45	20	31.25
Middle	3	20	14.45
End with unripe banana	12	20	3.2
Total	60	60	48.9

*Expected values must be those predicted by the null hypothesis provided in the student response, add up to 60, and include no cells equal to 0.

2015 #2c

(c)



Energy from hydrolysis of 30 mol ATP $= 30\text{ mol} \cdot 7.3 \frac{\text{kcal}}{\text{mol}} = \boxed{219\text{ kcal}}$

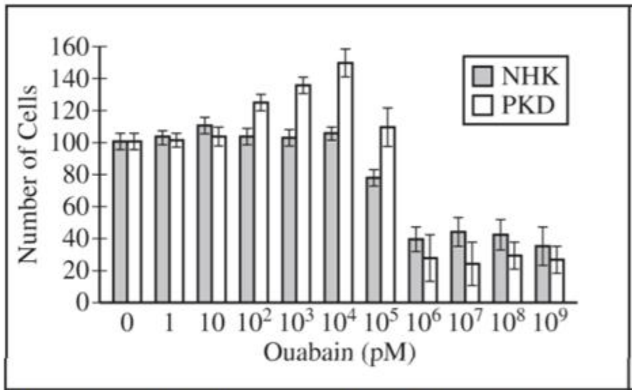
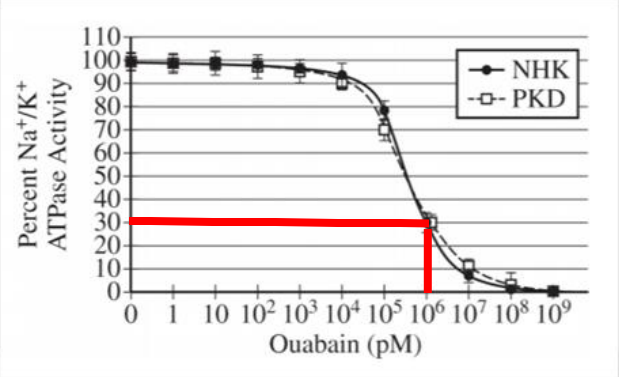
1 mol glucose $\cdot$ 30 mol ATP/mol glucose $= 30$ mol ATP $\Rightarrow$ 219 kcal

% Efficiency $= 219\text{ kcal} / 686\text{ kcal} \cdot 100\% = \boxed{31.9\%}$

Excess energy is lost to the environment as heat.

2016 #2b	
(b)	The growth rate between hours 2 and 4 is $\frac{10^4 \text{ cells/mL} - 10^1 \text{ cells/mL}}{2 \text{ hrs}} = 4995 \frac{\text{cells}}{\text{mL} \times \text{hr}}$

2019 #3c	
(c)	Male – X^mY, where m = mutation Female – XX X X X^m X^mX X^mX Y XY XY There is a 0% probability that a male offspring will have PDC deficiency.

2021 #1c	
	 Figure 1. Cell number compared with the number of cells at 0 pM ouabain. Normal human kidney (NHK) cells and polycystic kidney disease (PKD) cells were treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.  Figure 2. Percent Na^+/K^+ATPase activity of NHK and PKD cells treated with increasing concentrations of ouabain. Error bars represent $\pm 2SE_{\bar{x}}$.
(c)	$150 \; units\ of\ ATP \frac{hydrolyzed}{sec} \times 30\% \frac{Na}{P} ATPase\ activity = 45\ units\ of\ ATP\ hydrolyzed\ per\ second$

2022 #1c

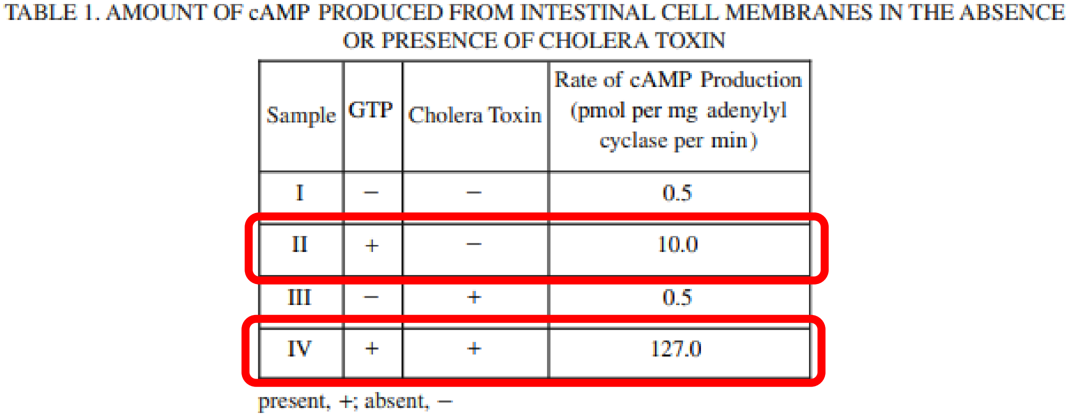
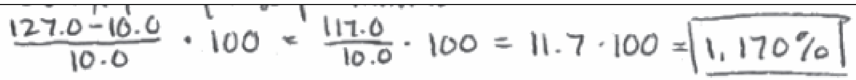


TABLE 1. AMOUNT OF cAMP PRODUCED FROM INTESTINAL CELL MEMBRANES IN THE ABSENCE OR PRESENCE OF CHOLERA TOXIN

Sample	GTP	Cholera Toxin	Rate of cAMP Production (pmol per mg adenylyl cyclase per min)
I	−	−	0.5
II	+	−	10.0
III	−	+	0.5
IV	+	+	127.0

present, +; absent, −

(c)



$$\frac{127.0-10.0}{10.0}\cdot 100 = \frac{117.0}{10.0}\cdot 100 = 11.7\cdot 100 = \boxed{1,170\%}$$

2023 #1c

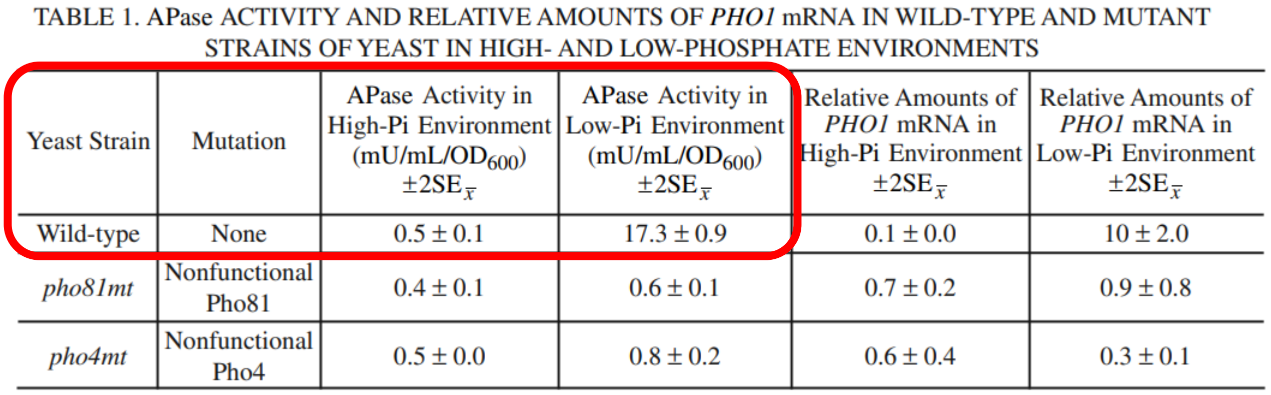
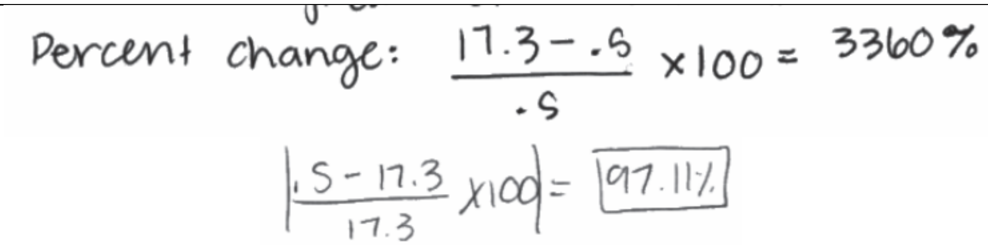


TABLE 1. APase ACTIVITY AND RELATIVE AMOUNTS OF *PHO1* mRNA IN WILD-TYPE AND MUTANT STRAINS OF YEAST IN HIGH- AND LOW-PHOSPHATE ENVIRONMENTS

Yeast Strain	Mutation	APase Activity in High-Pi Environment ($mU/mL/OD_{600}$) $\pm 2SE_{\bar{x}}$	APase Activity in Low-Pi Environment ($mU/mL/OD_{600}$) $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in High-Pi Environment $\pm 2SE_{\bar{x}}$	Relative Amounts of *PHO1* mRNA in Low-Pi Environment $\pm 2SE_{\bar{x}}$
Wild-type	None	0.5 ± 0.1	17.3 ± 0.9	0.1 ± 0.0	10 ± 2.0
pho81mt	Nonfunctional Pho81	0.4 ± 0.1	0.6 ± 0.1	0.7 ± 0.2	0.9 ± 0.8
pho4mt	Nonfunctional Pho4	0.5 ± 0.0	0.8 ± 0.2	0.6 ± 0.4	0.3 ± 0.1

(c)



Percent change: $\frac{17.3-.5}{.5}\times 100 = 3360\%$

$$\left|\frac{.5-17.3}{17.3}\times 100\right| = \boxed{97.11\%}$$

(note: this should be -97%)

2024 #2c

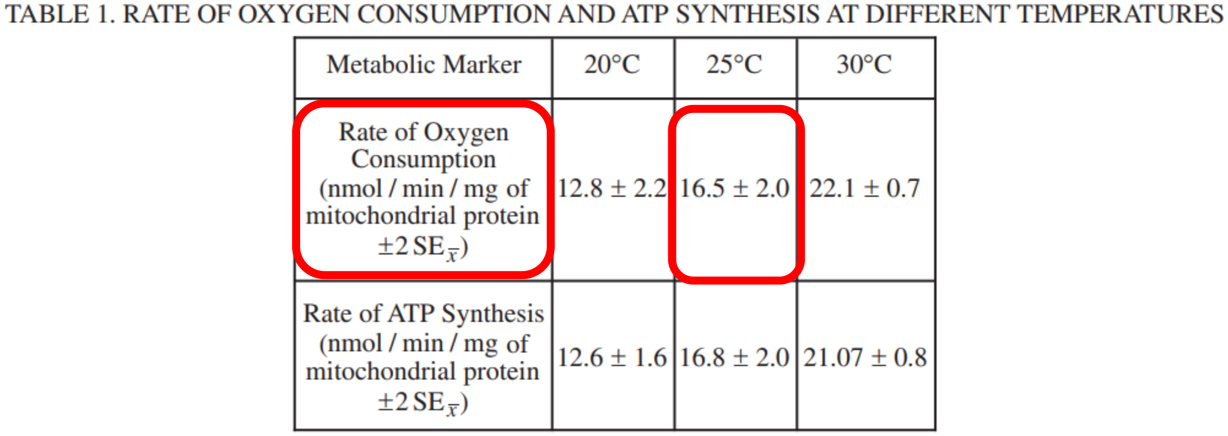
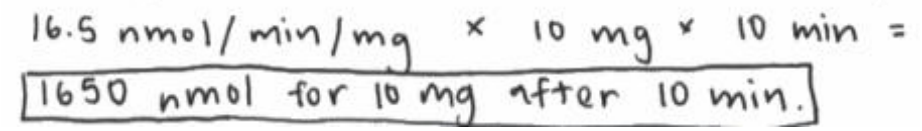


TABLE 1. RATE OF OXYGEN CONSUMPTION AND ATP SYNTHESIS AT DIFFERENT TEMPERATURES

Metabolic Marker	20°C	25°C	30°C
Rate of Oxygen Consumption (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.8 ± 2.2	16.5 ± 2.0	22.1 ± 0.7
Rate of ATP Synthesis (nmol / min / mg of mitochondrial protein $\pm 2\,SE_{\bar{x}}$)	12.6 ± 1.6	16.8 ± 2.0	21.07 ± 0.8

(c)



16.5 nmol/min/mg × 10 mg × 10 min =

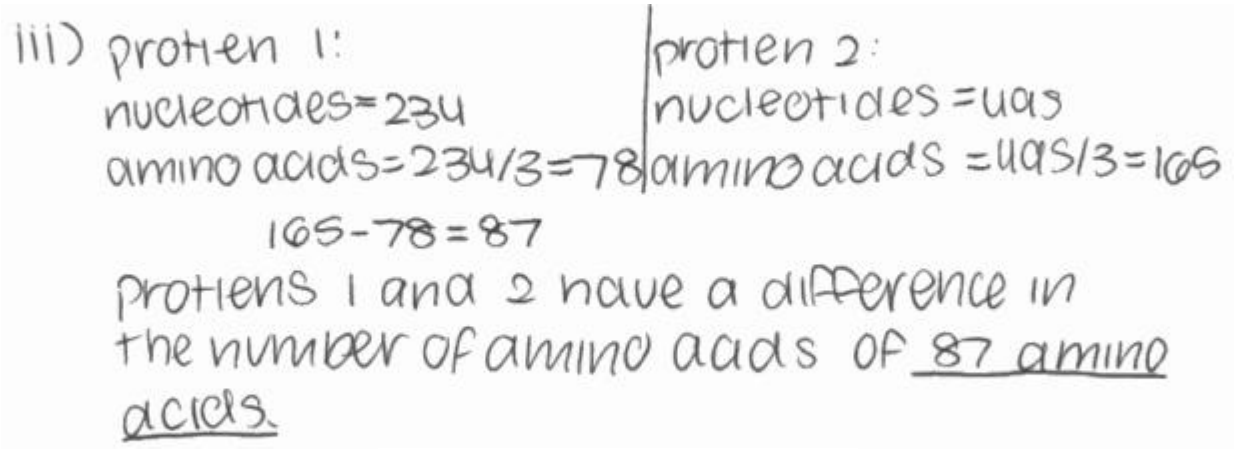
$\boxed{\text{1650 nmol for 10 mg after 10 min.}}$

1,650 [16.5 nmol/min/mg × 10 mg × 10 min]

2025 #1

(c)

iii. Protein 1 is encoded by 234 nucleotides, while protein 2 is encoded by 495 nucleotides. Assuming all nucleotides for both proteins encode amino acids, **calculate** the difference in the number of amino acids between the two proteins.



iii) protien 1:
nucleotides=234
amino acids=234/3=78

protien 2:
nucleotides =495
amino acids =495/3=165

165-78=87

protiens 1 and 2 have a difference in the number of amino acids of 87 amino acids.

- 87 (amino acids) [(495/3)−(234/3)]

2026 CED Q2

(c) ii.

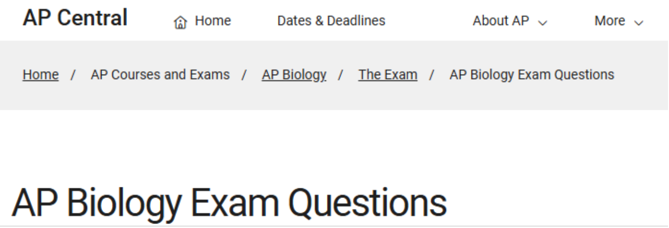
$$115{,}000\ cells\ x\ 85\%\ apoptosis = 97{,}750\ cells$$

- 97,750 (Acceptable range is 93,150 - 102,350)

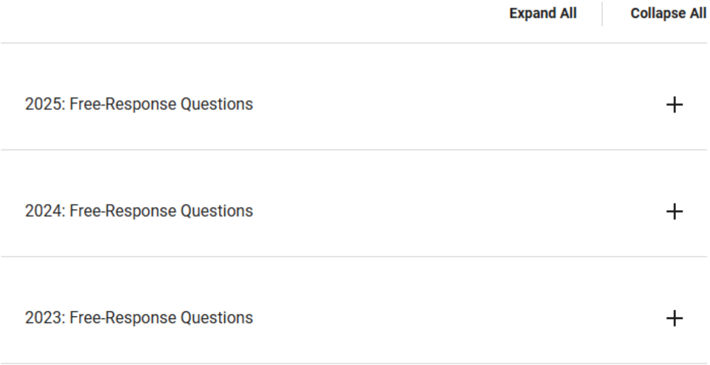
Example FRQ Responses

AP Central has the example responses for the past three years of the FRQs (2023 – 2025). Below are instructions to find the sample responses and scoring commentary for those responses.

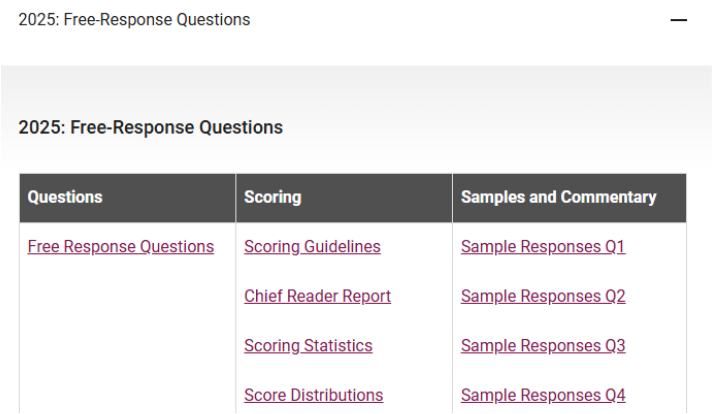
1. Go to [AP Central]()


AP Central
Home
Dates & Deadlines
About AP
More
Home / AP Courses and Exams / AP Biology / The Exam / AP Biology Exam Questions
AP Biology Exam Questions

2. Scroll to the year for the question of interest


Expand All
Collapse All
2025: Free-Response Questions +
2024: Free-Response Questions +
2023: Free-Response Questions +

3. Push the "+" button to expand the section


2025: Free-Response Questions –

2025: Free-Response Questions

Questions	Scoring	Samples and Commentary
Free Response Questions	Scoring Guidelines	Sample Responses Q1
	Chief Reader Report	Sample Responses Q2
	Scoring Statistics	Sample Responses Q3
	Score Distributions	Sample Responses Q4

4. Select the question you are looking for under "samples and commentary."

Special Notes:

- Scroll down on the sample response for information about which points the student got credit for and what they said to award that credit

Study Plans

This is designed as a study plan to allow you to prepare for the AP Bio Exam starting on January 24th or 100 days before the AP Bio Exam.

This is a schedule of what topics to study each day or tasks to complete, it is YOUR decision HOW you want to review these topics.

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Good Luck on your studying and remember...

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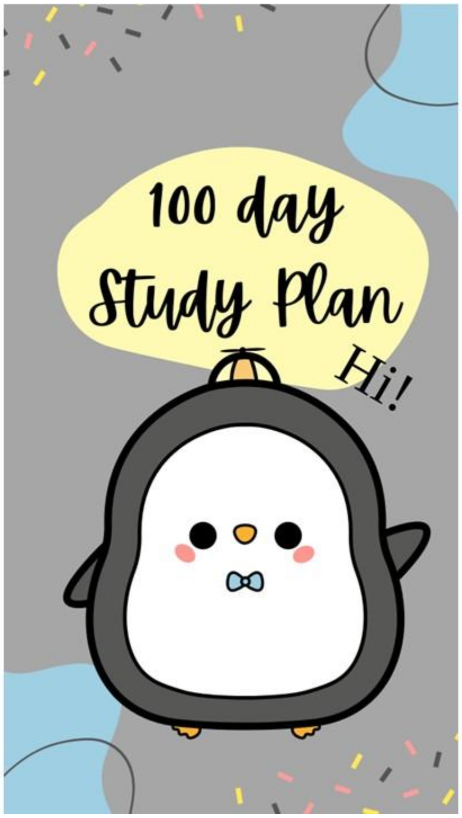


AP Bio Penguins Resource Suggestions:

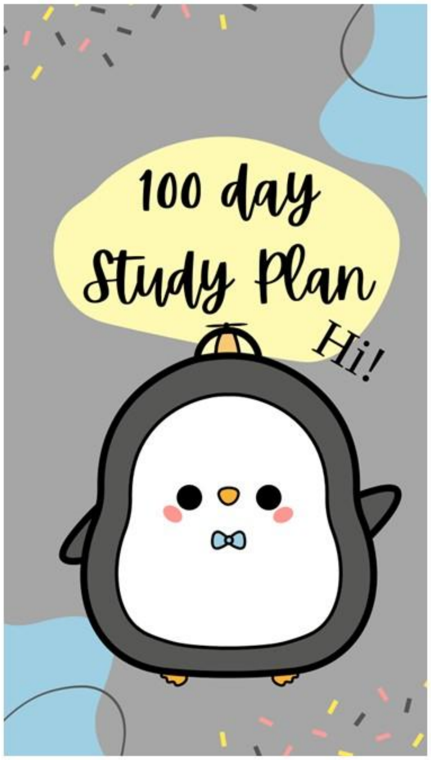
Topic Review:
- CED Topic TikToks
- Review Guide Topic Qs
- CED Topic Quizizz Games

Practice MCQs
- Review Guide Unit MCQs

Practice FRQs
- Review Guide Unit FRQs
- FRQ Fridays

Note: complete at least 2 FRQs each day of the FRQ Review, score yourself using the scoring guidelines and exemplar responses

Wayground (WG) Codes:
Unit 1 & 2 - 0882 8262
Unit 3 & 4 - 3189 6934
Unit 5 & 6 - 3923 6966
Unit 7 & 8 - 4290 6982

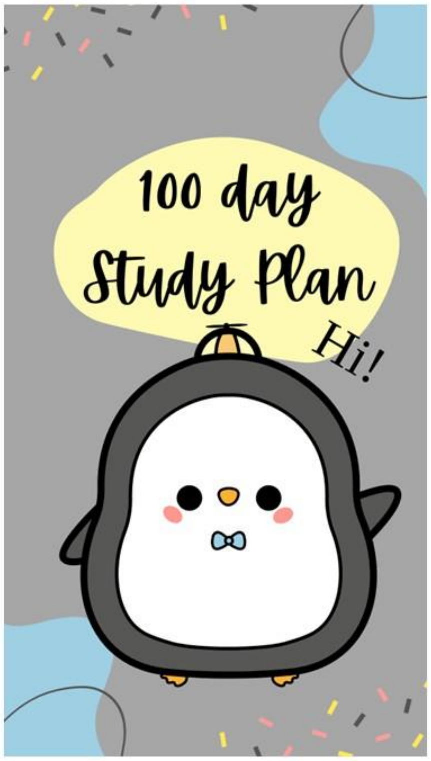


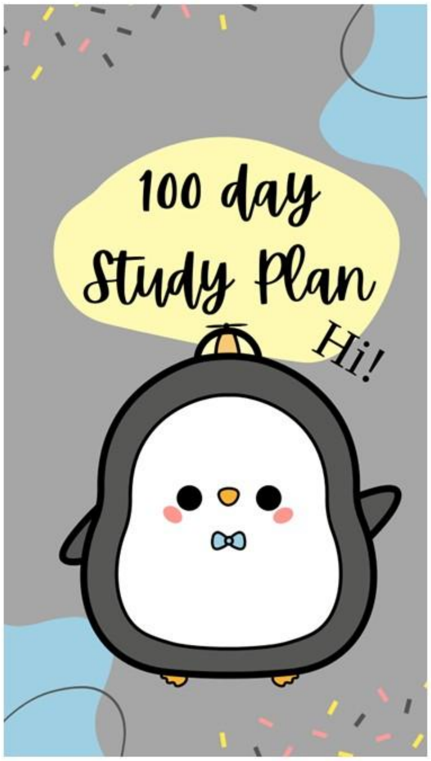
JANUARY 2026

S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24 PreTest 100 days until...
25 1.1 99 days until...	26 1.2 98 days until...	27 1.3 97 days until...	28 1.4 96 days until...	29 1.5 95 days until...	30 1.6 94 days until...	31 1.7 93 days until...

FEBRUARY 2026

S	M	T	W	T	F	S
1 Unit 1 MCQ Practice 92 days until...	2 BREAK 91 days until...	3 2.1 90 days until...	4 2.2 89 days until...	5 2.3 88 days until...	6 2.4 87 days until...	7 2.5 86 days until...
8 2.6 85 days until...	9 2.7 84 days until...	10 2.8 83 days until...	11 2.9 82 days until...	12 2.10 81 days until...	13 Unit 2 MCQ Practice 80 days until...	14 Unit 2 FRQ Practice 79 days until...
15 Unit 2 FRQ Practice 78 days until...	16 BREAK 77 days until...	17 3.1 76 days until...	18 3.2 75 days until...	19 3.3 74 days until...	20 3.4 73 days until...	21 3.5 72 days until ...
22 Unit 3 MCQ Practice 71 days until...	23 Unit 3 FRQ Practice 70 days until...	24 Unit 3 FRQ Practice 69 days until...	25 BREAK 68 days until...	26 4.1 67 days until...	27 4.2 66 days until...	28 4.3 65 days until...



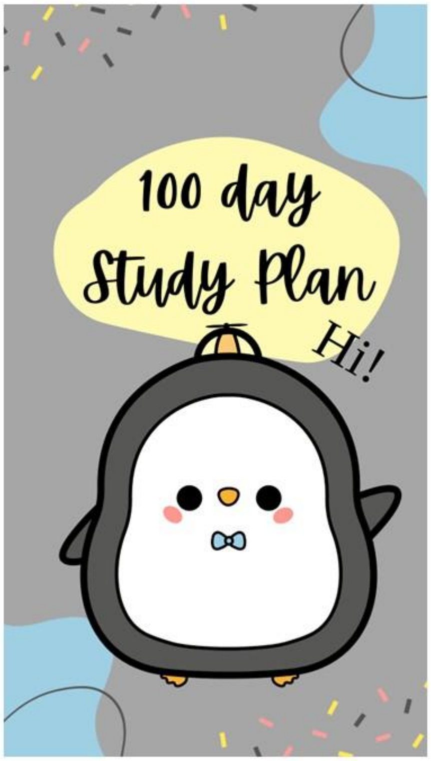


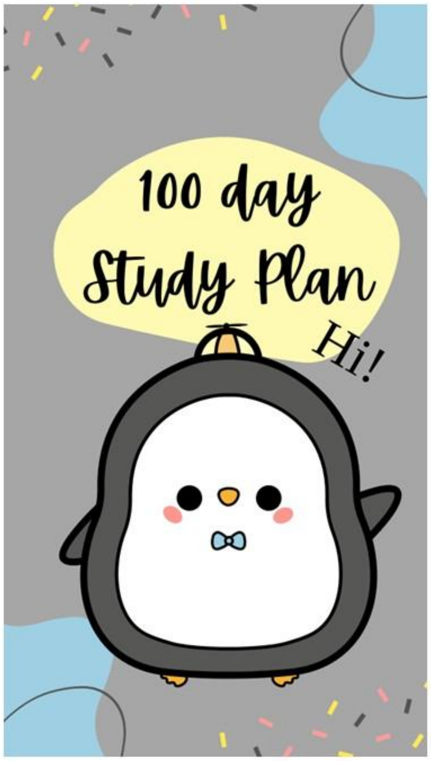
MARCH 2026

S	M	T	W	T	F	S
1 4.4 64 days until...	2 4.5 63 days until...	3 4.6 62 days until...	4 Unit 4 MCQ Practice 61 days until...	5 Unit 4 FRQ Practice 60 days until...	6 Unit 4 FRQ Practice 59 days until...	7 BREAK 58 days until...
8 5.1 57 days until...	9 5.2 56 days until...	10 5.3 55 days until...	11 5.4 54 days until...	12 5.5 53 days until...	13 Unit 5 MCQ Practice 52 days until...	14 Unit 5 FRQ Practice 51 days until...
15 Unit 5 FRQ Practice 50 days until...	16 BREAK 49 days until...	17 6.1 48 days until...	18 6.2 47 days until...	19 6.3 46 days until...	20 6.4 45 days until...	21 6.5 44 days until...
22 6.6 43 days until...	23 6.7 42 days until...	24 6.8 41 days until...	25 Unit 6 MCQ Practice 40 days until...	26 Unit 6 FRQ Practice 39 days until...	27 Unit 6 FRQ Practice 38 days until...	28 BREAK 37 days until...
29 7.1 36 days until...	30 7.2 35 days until...	31 7.3 34 days until...				

APRIL 2026

S	M	T	W	T	F	S
			1 7.4 33 days until…	2 7.5 32 days until…	3 7.6 31 days until…	4 7.7 30 days until…
5 7.8 29 days until…	6 7.9 28 days until…	7 7.10 27 days until…	8 7.11 26 days until…	9 7.12 25 days until…	10 Unit 7 MCQ Practice 24 days until…	11 Unit 7 FRQ Practice 23 days until…
12 Unit 7 FRQ Practice 22 days until…	13 Unit 7 FRQ Practice 21 days until…	14 BREAK 20 days until…	15 8.1 19 days until…	16 8.2 18 days until…	17 8.3 17 days until…	18 8.4 16 days until…
19 8.5 15 days until…	20 8.6 14 days until…	21 8.7 13 days until…	22 Unit 8 MCQ Practice 12 days until…	23 Unit 8 FRQ Practice 11 days until…	24 Unit 8 FRQ Practice 10 days until….	25 Unit 8 FRQ Practice 9 days until…
26 BREAK 8 days until….	27 Unit 1 & 2 CED WG 7 days until…	28 Unit 3 & 4 CED WG 6 days until….	29 Unit 1 – 4 Review Video 5 days until…	30 Unit 5 & 6 CED WG 4 days until…		





MAY 2026

S	M	T	W	T	F	S
					1 Unit 7 & 8 CED WG 3 days until…	2 Unit 5 – 8 Review Video 2 days until…
3 BREAK 1 day until…	4 AP Bio Exam @ 8 AM	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

This is designed as a study plan to allow you to prepare for the AP Bio Exam starting on March 8th or 57 days before the AP Bio Exam.

This is a schedule of what units to study each day or tasks to complete, it is YOUR decision HOW you want to review these units.

You may use the suggested resources from AP Bio Penguins or find additional resources of your own like Review Books, YouTube creators, Review websites...

Good Luck on your studying and remember...

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8 week
Study Plan

AP Bio Penguins Resource Suggestions:

Content Review:
CED Topic TikToks
Unit Review Videos
Topic Qs in Review Guide

Practice MCQs
Review Guide Unit MCQs

Practice FRQs
Review Guide Unit FRQs

Note: Complete at least 4 FRQs on the FRQ Review day, score yourself using the scoring guidelines and exemplar responses

Wayground (WG) Codes:
Unit 1 - 5535 8822
Unit 2 - 3124 1574
Unit 3 - 3373 1942
Unit 4 - 2324 6182
Unit 5 - 4736 3430
Unit 6 - 6204 3494
Unit 7 - 1747 9014
Unit 8 - 4683 9142

8 week
Study Plan

MARCH 2026

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8 Unit 1 CED Quizizz 57 days until...	9 Unit 1 Topic Review 56 days until...	10 Unit 1 Topic Review 55 days until...	11 Unit 1 Topic Review 54 days until...	12 Unit 1 MCQ Practice 53 days until...	13 Unit 1 FRQ Practice 52 days until...	14 BREAK 51 days until...
15 Unit 2 CED Quizizz 50 days until...	16 Unit 2 Topic Review 49 days until...	17 Unit 2 Topic Review 48 days until...	18 Unit 2 Topic Review 47 days until...	19 Unit 2 MCQ Practice 46 days until...	20 Unit 2 FRQ Practice 45 days until...	21 BREAK 44 days until...
22 Unit 3 CED Quizizz 43 days until...	23 Unit 3 Topic Review 42 days until...	24 Unit 3 Topic Review 41 days until...	25 Unit 3 Topic Review 40 days until...	26 Unit 3 MCQ Practice 39 days until...	27 Unit 3 FRQ Practice 38 days until...	28 BREAK 37 days until...
29 Unit 4 CED Quizizz 36 days until...	30 Unit 4 Topic Review 35 days until...	31 Unit 4 Topic Review 34 days until...				

APRIL 2026

S	M	T	W	T	F	S
			1 Unit 4 Topic Review 33 days until...	2 Unit 4 MCQ Practice 32 days until...	3 Unit 4 FRQ Practice 31 days until...	4 BREAK 30 days until...
5 Unit 5 CED Quizizz 29 days until...	6 Unit 5 Topic Review 28 days until...	7 Unit 5 Topic Review 27 days until...	8 Unit 5 Topic Review 26 days until...	9 Unit 5 MCQ Practice 25 days until...	10 Unit 5 FRQ Practice 24 days until...	11 BREAK 23 days until...
12 Unit 6 CED Quizizz 22 days until...	13 Unit 6 Topic Review 21 days until...	14 Unit 6 Topic Review 20 days until...	15 Unit 6 Topic Review 19 days until...	16 Unit 6 MCQ Practice 18 days until...	17 Unit 6 FRQ Practice 17 days until...	18 BREAK 16 days until...
19 Unit 7 CED Quizizz 15 days until...	20 Unit 7 Topic Review 14 days until...	21 Unit 7 Topic Review 13 days until...	22 Unit 7 Topic Review 12 days until...	23 Unit 7 MCQ Practice 11 days until...	24 Unit 7 FRQ Practice 10 days until....	25 BREAK 9 days until...
26 Unit 8 CED Quizizz 8 days until....	27 Unit 8 Topic Review 7 days until...	28 Unit 8 Topic Review 6 days until....	29 Unit 8 Topic Review 5 days until...	30 Unit 8 MCQ Practice 4 days until...		

8 week
Study Plan

8 week
Study Plan

MAY 2026

S	M	T	W	T	F	S
					1 Unit 8 FRQ Practice 3 days until...	2 YT Cram Session 2 days until...
3 BREAK 1 day until...	4 AP Bio Exam @ 8 AM	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

This is designed as a study plan to allow you to prepare for the AP Bio Exam starting on April 5th or 29 days before the AP Bio Exam.

This is a schedule of what units to study each day or tasks to complete, it is YOUR decision HOW you want to review these units.

You may use the suggested resources from AP Bio Penguins or find additional resources of your own like Review Books, YouTube creators, Review websites...

Good Luck on your studying and remember...

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4 week
Study Plan

AP Bio Penguins Resource Suggestions:

Content Review:
Unit Review Videos

Practice MCQs
Review Guide Unit MCQs

Practice FRQs
Review Guide Unit FRQs

Note: Complete at least 4 FRQs on the FRQ Review day, score yourself using the scoring guidelines and exemplar responses

Wayground (WG) Codes:
Unit 1 & 2 - 0882 8262
Unit 3 & 4 - 3189 6934
Unit 5 & 6 - 3923 6966
Unit 7 & 8 - 4290 6982

APRIL 2026

S	M	T	W	T	F	S
			1	2	3	4
5 Unit 1 & 2 CED Quizizz 29 days until...	6 Unit 1 Review 28 days until...	7 Unit 2 Review 27 days until...	8 U1 & 2 MCQ Practice 26 days until...	9 Unit 1 FRQ Practice 25 days until...	10 Unit 2 FRQ Practice 24 days until...	11 BREAK 23 days until...
12 Unit 3 & 4 CED Quizizz 22 days until...	13 Unit 3 Review 21 days until...	14 Unit 4 Review 20 days until...	15 U3 & 4 MCQ Practice 19 days until...	16 Unit 3 FRQ Practice 18 days until...	17 Unit 4 FRQ Practice 17 days until...	18 BREAK 16 days until...
19 Unit 5 & 6 CED Quizizz 15 days until...	20 Unit 5 Review 14 days until...	21 Unit 6 Review 13 days until...	22 U5 & 6 MCQ Practice 12 days until...	23 Unit 5 FRQ Practice 11 days until...	24 Unit 6 FRQ Practice 10 days until....	25 BREAK 9 days until...
26 Unit 7 & 8 CED Quizizz 8 days until....	27 Unit 7 Review 7 days until...	28 Unit 8 Review 6 days until....	29 U7 & 8 MCQ Practice 5 days until...	30 Unit 7 FRQ Practice 4 days until...		

4 week
Study Plan

4 week
Study Plan

MAY 2026

S	M	T	W	T	F	S
					1 Unit 8 FRQ Practice 3 days until...	2 YT Cram Session 2 days until...
3 BREAK 1 day until...	4 AP Bio Exam @ 8 AM	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

This is designed as a study plan to allow you to prepare for the AP Bio Exam starting on April 24th or 10 days before the AP Bio Exam.

This is a CRAM schedule so use resources that provide an overview of the content and spot check your weaknesses.

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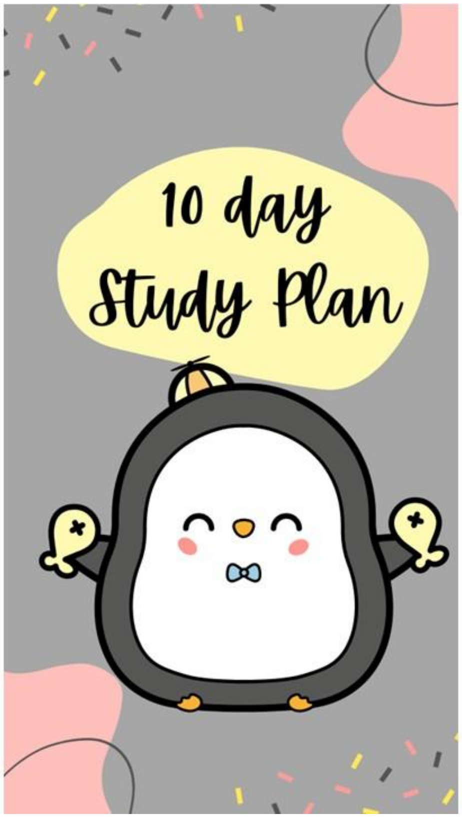
Good Luck on your studying and remember...

AP Bio Penguins are Dressed for Success!



AP Bio Penguins Resource Suggestions:

Content Review:
Unit Review Videos

Practice MCQs
Review Guide Unit MCQs

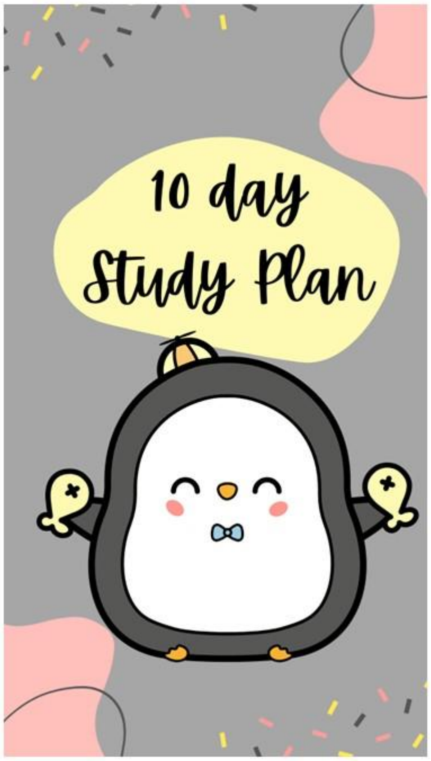
Practice FRQs
Review Guide Unit FRQs

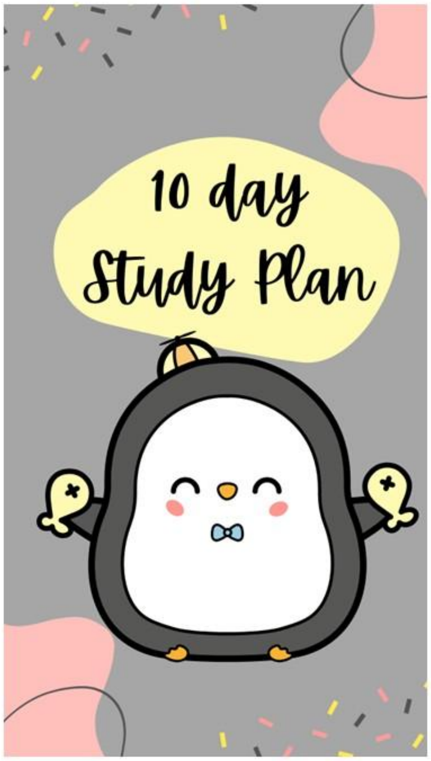
Note: Complete at least 2-3 FRQs each day (not including 2024 FRQs), score yourself using the scoring guidelines and exemplar responses

Wayground (WG) Codes:
Unit 1 - 5535 8822
Unit 2 - 3124 1574
Unit 3 - 3373 1942
Unit 4 - 2324 6182
Unit 5 - 4736 3430
Unit 6 - 6204 3494
Unit 7 - 1747 9014
Unit 8 - 4683 9142

APRIL 2026

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24 U1 Review & MCQ/FRQ 10 days until....	25 U2 Review & MCQ/FRQ 9 days until...
26 U3 Review & MCQ/FRQ 8 days until....	27 U4 Review & MCQ/FRQ 7 days until...	28 U5 Review & MCQ/FRQ 6 days until....	29 U6 Review & MCQ/FRQ 5 days until...	30 U7 Review & MCQ/FRQ 4 days until...		





MAY 2026

S	M	T	W	T	F	S
					1 U8 Review & MCQ/FRQ 3 days until...	2 YT Cram U1-4 WG 2 days until...
3 2025 FRQ U5-8 WG 1 day until...	4 AP Bio Exam @ 8 AM	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30